Industrial QUALITY CONTROL

JANUARY, 1953 VOL. IX, NO. 4

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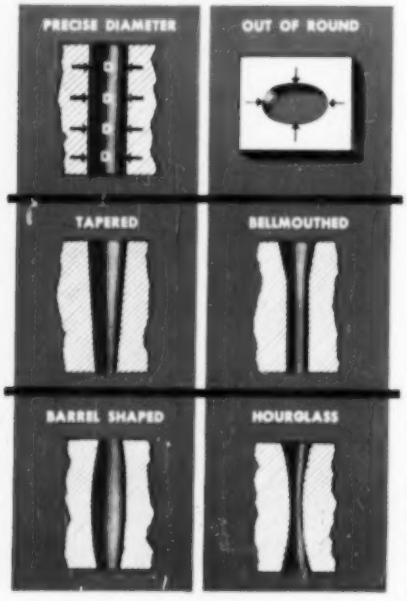

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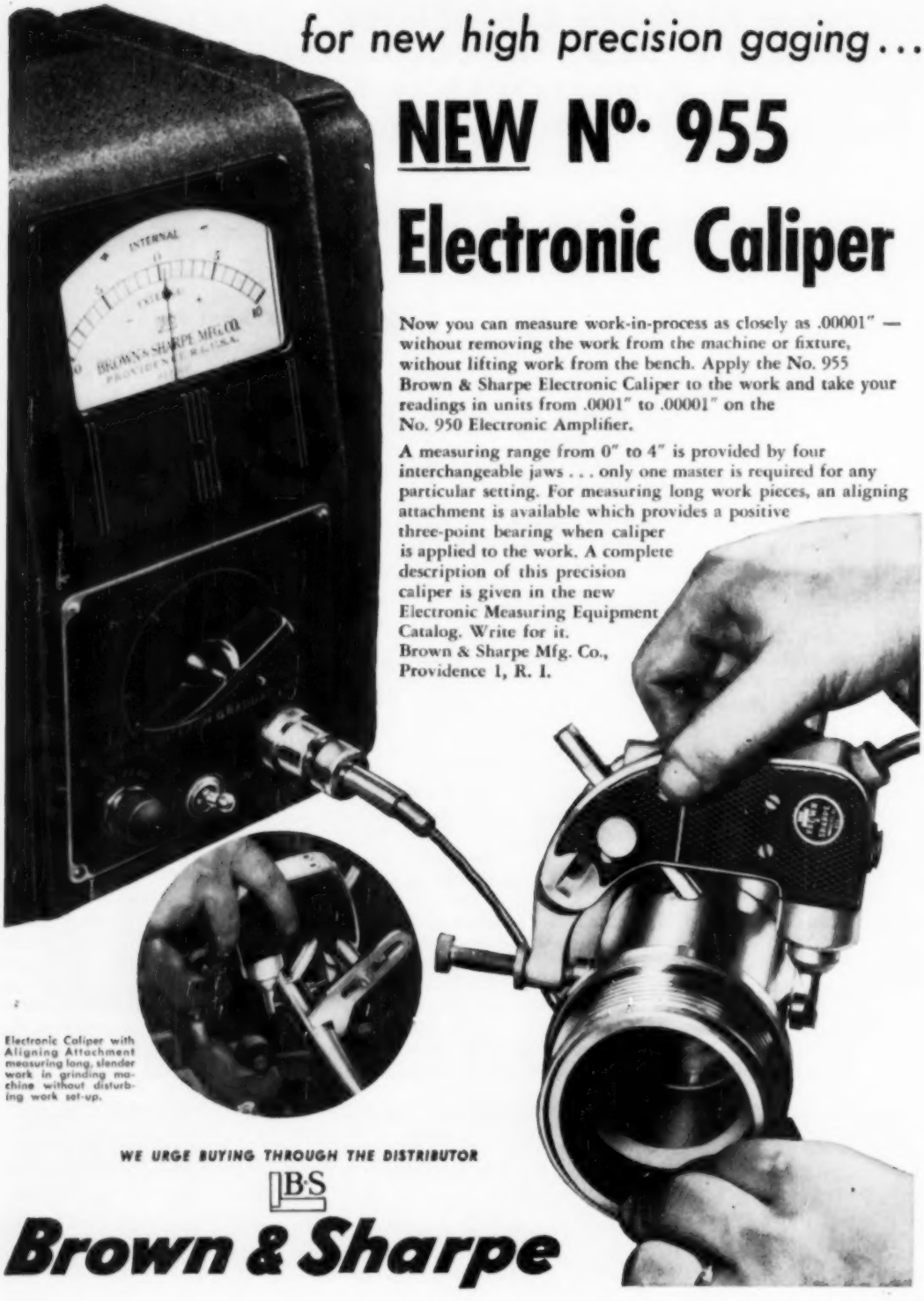

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Industrial Quality Control

Vol. IX JANUARY, 1953 No. 4

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THIS WORD "STATISTICAL"

What shall we do about "statistical?" Some think we ought to avoid it wherever possible, and only whisper it when we do use it. Others think it is the very heart of our activity. What shall we do and how can we get together on the word?

Those who dislike using "statistical" seem to have about three objections: There have been too many irresponsible or untrained people "slinging statistics." Some go out to "prove" a contention by statistics. They keep on gathering data until they have enough to look impressive (if they throw away enough counter evidence!), then they stop and report their "findings." Need I say that certain politicians and advertisers are of this stamp? Of course a great many more people reach false conclusions through "statistics" because they are ignorant either of sound methods of gathering facts or of proper analysis of the resulting data or they are subconsciously biased. The antidote for all this is for us all to be better trained statistically so that we will not be so easily fooled.

A second objection to "statistics" is that many think of bushels of tables and nasty looking formulas—dry, incomprehensible and boring. Clear and interesting charts with a simple, straightforward and sound explanation can take care of this objection. Also what is more interesting than a chart about "my" work or "my" department or company?

Finally you cannot pronounce the wretched word! Of course not, if you try to take it in one gulp with s's and t's thrown in at random spots, as in a hiccup. The way to do it is to take it in three bites: "sta" "tis" "tics".

Now what about the word "statistics," is it worth popularizing? I am convinced so. It really is the heart of our new science of quality control. Let us see how we can popularize it:

Everywhere there is variation—in product quality, machine performance, raw materials, measurement errors, laboratory results, human performance and plant conditions. Hence a series of results on any quality characteristic will show variation. Thus these results are varying data, and whether we like it or not they are therefore "statistical data." Now what is more natural in analyzing such data than to use the very methods which were developed for just this type of data: "statistical methods?" We use a plane to make a board smooth, because it is designed for the job. "Statistical methods" give us a kit of tools carefully designed for analyzing varying data.

Why do we need this kit of tools? Because we must make decisions from our data and we want these decisions to be the soundest we can make. Moreover we do not want to reach a decision if the data do not justify one. Now it is true that there are many cases where no high-powered statistical tool is needed because the trouble or decision is so obvious. I should be the last one to urge the use of a statistical tool if the conclusion really is obvious. But many a conclusion which seems obvious is not warranted by the data and is actually false! Statistical methods can greatly help us by determining our risks of wrong decisions and helping us control them within economical levels. If data are worth gathering at all, they are worth analyzing properly.

Finally we must show people how simple and straight-forward statistical quality control can be. There is much room for all of us to learn how to present our charts and stories more clearly.

So let us not be afraid of the word "statistical," but sell it to others and be proud of it. It is the part of our science which is unique and wherein we can best help our organization.

Irving W. Burr

Our Cover

The poster, which is the subject of this month's colorful cover, was sent to us by Mr. J. E. Meyers of International Harvester's Farmall Division at Rock Island.

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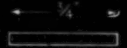
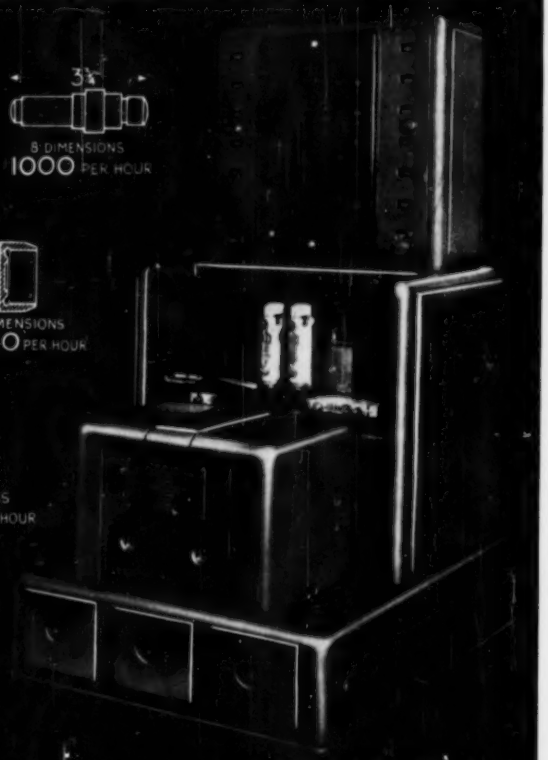


1 DIMENSION
10000 PER HOUR



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An Attribute Chart for Acceptance Purposes

FAY CARLSON

Sundstrand Machine Tool Company

THERE are three alternatives regarding inspection of parts; inspect all of the parts, inspect a sample of the parts, or inspect none of the parts. Occasionally a product is of a nature that literally no inspection is required. However, in all instances where parts are of a precision nature or have some functional purpose, inspection is a requisite. Prior to statistical quality control, this meant 100% screening, at the attendant high cost, or a spot check. If a spot check were used, someone would interpret the findings and a decision would be made to accept the material without further inspection or proceed with 100% screening. Unfortunately, interpretations varied widely, and all too frequently an inordinate amount of time was spent screening lots of an essentially acceptable character or passing material that contained undesirable quantities of scrap.

With the advent of statistical methods, discreet sample sizes and acceptance criteria were provided for any desired quality level and lot size. As confidence in these plans increased, sampling inspection replaced 100% inspection to a greater and greater degree. Experience has demonstrated to all of us at one time or another how the element of fatigue and distraction can undermine the efficiency of 100% inspection.

As beneficial as these sampling plans are, the fact remains that manufacturing must proceed at or about Acceptable Quality Level percent defective or screening will result regardless. This fact refocused attention on what has always been the backbone of any successful inspection effort: Patrol of Machine Line Inspection. The logic of concentrating as much inspection effort as possible at the point of origin of the dimension has long been acknowledged, for only at the machine does the opportunity exist to influence the physical characteristics of the part. As thinking proceeds in this vein, the idea occurs that the volume of machine line inspection could be geared to a set of sampling tables which would make acceptance of material contingent upon the line inspector's findings and relegate bench inspection to the function of screening unacceptable orders. In this way, emphasis on line inspection can be increased at the expense of bench inspection, a needless duplication of effort can be eliminated, and the flow of material can be expedited.

Although several common charts are universally used for process control, such as the $\bar{X}$,R chart, the p chart, and the c chart, they are not readily adaptable to this purpose. This is especially true when as many as twenty or more dimensions are being generated at one time.

There is, however, a chart which very successfully fulfills these requirements. This chart, the Attribute Chart, originated by Lloyd V. Carter of the Air Material Command for use specifically in conjunction with MIL-STD-105A, has a versatility that makes it applicable in a wide range of situations.

To illustrate the application of the chart, let us take a lot of 200 gears. By consulting the route card that accompanies the work we may enter onto the chart (See Figure 1) the Part Name, Order Number, Part Number, Lot Size, and Operation Number. The Date, Inspector's Clock Number, Operator's Clock Number, Department Number, and Machine Number may be entered in from common knowledge.

Entering Table III of MIL-STD-105A with the lot size, we find the proper sample size letter under Inspection Level II. If the lot size is 200, the sample size letter is H. Entering Table IV-A with Sample Size Letter H, we find that the appropriate Single Sample Size for our lot size is 35.

An Acceptable Quality Level (AQL) must then be established. If we set the AQL at 1.5%, we find that the appropriate rejection number is 2. (Table IV-A).

The inspector's object now is to carry out a periodic inspection such that 35 pieces will have been checked when the lot reaches completion, and at an interval which will permit the heading off and correction of out of tolerance conditions.

In order to establish a rational inspection interval and sub-sample size, we divide the sample size into the lot size. The result will identify

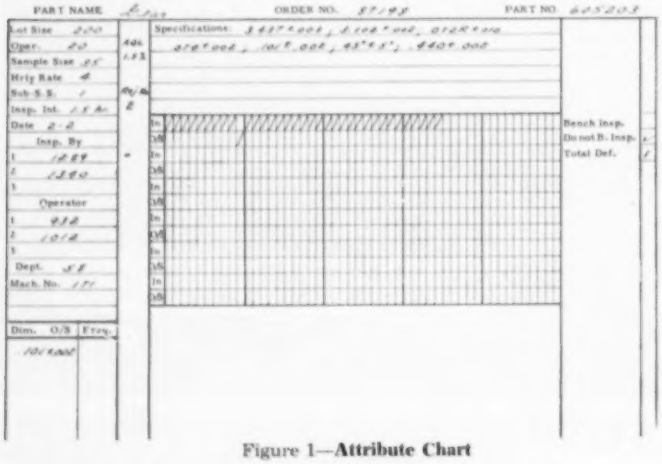


Figure 1—**Attribute Chart**

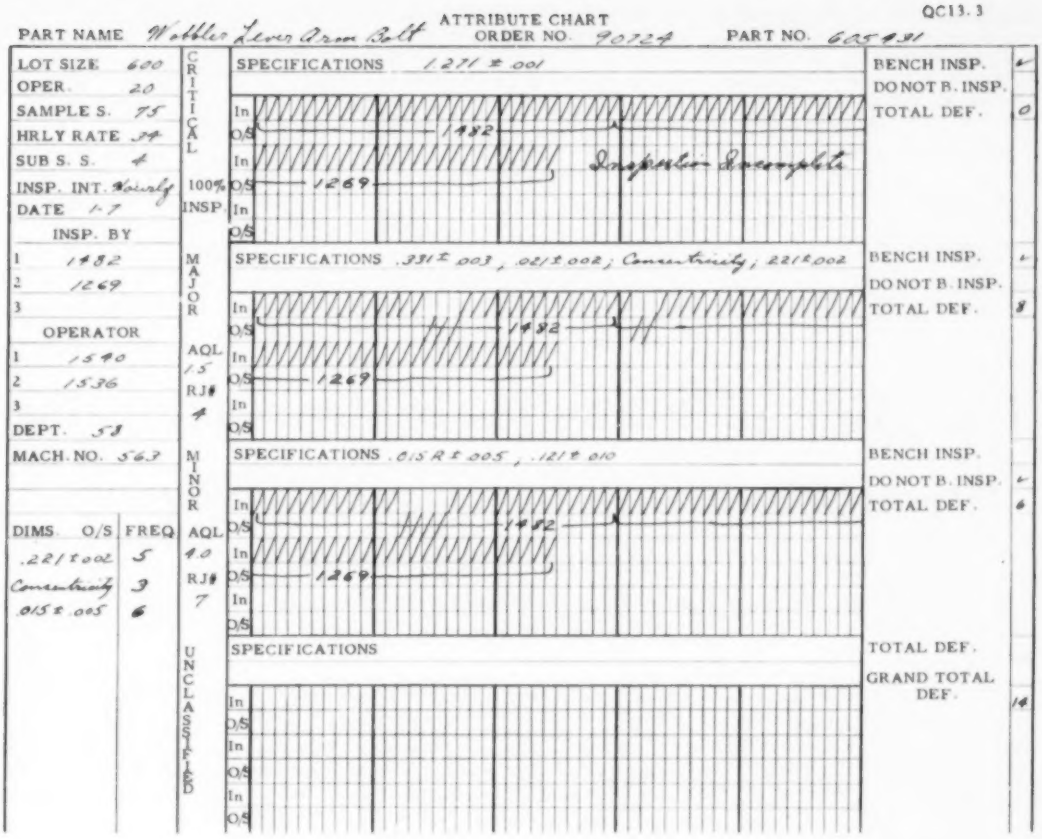


Figure 2—**Attribute Chart with Classification of Defects**

which specific pieces we would inspect for an evenly distributed sample, such as every sixth piece or every tenth piece. Since it is neither practical nor desirable to take an evenly distributed sample where line inspection is concerned, we divide the result of our initial division into the hourly rate of production to find the number of pieces that would have to be checked each hour. This may then be converted to a practical time interval and sub-sample size. Taking the instance under discussion, if hourly production averages 4 an hour, we have first 200/35 = 5.7 and then 4/5.7 = .7. Therefore, one piece each hour and a half is a reasonable sub-sample size and time interval. The inspector uses this as a guide for his efforts. He is not required to be there on the minute nor does the work progress at a precise hourly rate. However, by observation of the work's progress the inspector may make compensation in the volume of inspection.

Each piece is checked for all dimensions. If the piece is found to be in tolerance on all dimensions, a diagonal line is drawn through a square in the IN (in specification) row. If one or more dimensions are found to be out of tolerance, a diagonal line is drawn through the O S (out of specification) row. The dimensions found out of tolerance are entered in the column headed Dims. O S and the frequency of occurrence tallied under the Freq. heading.

In this way, each piece in the sample is inspected and its status as acceptable or non-acceptable is registered on the chart, and if non-acceptable the reason for non-conformance stated. The last piece run is always inspected at the periodic inspections, as it is held to be most nearly representative of the condition of the operation at that point. If the piece is found to be defective, corrective action is, of course, initiated.

When the lot is completed, the number of defective pieces is compared to the rejection number. If the defectives are equal to or greater than the rejection number the lot is diverted to the bench and 100% inspection carried out on the dimensions found to be defective.

The point is immediately raised that in introducing a condition of periodic sampling, the principle of random selection has been compromised and the Operating Characteristic curve for the sampling plan inevitably altered.

The fact is that the element of randomness is not destroyed. As has

been pointed out, the hourly rate of production does vary, therefore there are no specific pieces foreordained for selection. Also the sampling plan becomes more discriminating rather than less for the following reason.

When sampling is applied to a finished order of material, as is done conventionally, the occurrence of defective pieces in the sample is representative of defectiveness in the lot. The occurrence of defectives in the use of the Attribute Chart is also representative of defectiveness in the lot but it projects a degree of defectiveness that is greater than actually exists when the results are subjected to the acceptance criteria. When an out of tolerance condition is found on the line, it is corrected, therefore the occurrence of a defective is representative only of such defectives as may have been generated immediately prior to the findings of the defective in the sample. If the interval of inspection is rational, the probability of accumulation of large quantities of scrap is small, and so we see that we have not jeopardized our quality by the use of this chart.

The Attribute Chart may then be said to provide an inspector's work report, a rational guide to periodic patrol inspection with overtones of process control, a history of processing difficulties, and a valid basis for acceptance of material. If used in conjunction with a classification of defects as shown in Figure 2, it can provide a realistic means of establishing an efficient volume of inspection.

The Role of Statistics in Increasing the Productivity of Industrial Research*

CHARLES A. BICKING

(Formerly with Hercules Powder Company)

Research and Development Division, Office, Chief of Ordnance

INTRODUCTION

A part of the content of the statistical approach to experimentation may seem naive to the experienced research worker. Laplace, an early student of probability, said of his work that it was basically common sense reduced to calculation.

CONDITIONS OF PRODUCTIVITY

When this kind of common sense is applied to the real problems of industrial research laboratories, there are at least two conditions which point up the fundamental simplicity of the approach.

It will be found that the individual experimenter is not always dealing with problems of primary measurement nor, even when the problem is of major importance, with the whole scope of the research project. Rather, most researchers are likely to be concerned with relatively insignificant day-to-day problems like the effect of a small change in conditions on output of a process, a comparison between instruments or technicians, or a change in specifications which will give a slight competitive superiority to the product. There are, perhaps, nine of these little problems to every one of the big ones requiring a major effort in the application of statistical methods. In spite of their individual insignificance, in mass the small problems probably account for the greatest part of the available increase in productivity of research.

Refined statistical techniques are not required for the solution of many of these simpler problems, and trial of some of the "rough and ready" techniques that are available is often very successful. From a practical standpoint, results are what count and not the theoretical purity nor rigor of an approach. As a matter of fact, it is not unreasonable nor indefensible to state that too much insistence on "high powered" methods will ruin statistics for most industrial uses, whether in research or elsewhere.

A second condition met with at the action level is that not all of those who may be called upon to exercise common sense are at the top in their scientific field nor are they always men of exceptional insight and judgment. Even the most experienced investigator will find that the statistical way of thinking supplements and confirms his judg-

TABLE 1—**Sources of Increased Research Productivity**

1. Reduction in amount of experimental work.
   a. By getting more information for the same amount of work by substituting factorial for classical designs.
   b. By using partial designs which drop all but essential information through use of such devices as Latin Squares, incomplete blocks or fractional replication.
2. Improvement in the reliability of results by making more certain and specific measurements of the sources of error.
3. Improvement in the quality of interpretation of results by planned coverage of foreseeable aspects of a problem.
4. Improvement in the effectiveness of presentation of results for decision and action.

*Presented at the Gordon Research Conference, American Association for the Advancement of Science, New Hampton, N. H., 27 July 1951.

TABLE 2—**Factorial Design for Study of Brittle Temperature of Sheeted Vinyl Plastic**

Mill	1																2													
Mold	1								2								1								2					
Section	A		B		C		D		A		B		C		D		A		B		C		D		A		B		C		D	
Tester	S	J	S	J	S	J	S	J	S	J	S	J	S	J	S	J	S	J	S	J	S	J	S	J	S	J	S	J	S	J	S	J
Area X																														
Age 2 Days	27						27			25											24					28				23	
1 Week					21				25						26					25											
4 Weeks			27										25				26						28			23					
Area Y																														
Age 2 Days						25				23										27				25				24		
1 Week	28			23			26					27				25	27										28				24
4 Weeks											27											27			27						
Area Z																														
Age 2 Days			25									23				27		25													
1 Week		25				25	27		29										27			23	25		26			27			
4 Weeks																													26		27	

NOTE: Test results for only the runs actually made according to a fractional experimental plan are shown.

ment and helps make it objective. This is especially true when experimental differences are not large and a clear-cut decision cannot be made. But statistical methods are particularly useful to an inexperienced research man whether he attains competence in the statistical approach himself or whether the application is engineered by an experienced statistician. Here again, the weight of many small gains in productivity is great.

It is of interest to list the sources of increased productivity in research, as in Table 1, and supply some examples.

EXAMPLES OF INCREASED PRODUCTIVITY

Two examples may serve to illustrate how productivity of industrial research has been improved.

Example A

A device of great effectiveness in reducing the number of experimental runs required to get all the essential information out of an investigation is the fractional replication of a factorial design. This experimental design was applied with good effect to the examination of the sources of variation in the brittle temperature of sheeted vinyl plastic. Brittle temperature is the temperature in degrees centigrade at which a test specimen of the material will fracture when subjected to a known shock. Many of the conditions involved in preparation and testing of the samples were suspected of affecting brittle temperature. Six of the conditions considered to be most important were chosen for examination; three of them at two levels each, two at three levels, and one at four levels. The factorial design to maximize information was, therefore, a block of 2 x 2 x 2 x 3 x 3 x 4 or 288 runs. The skeleton design is given in Table 2.

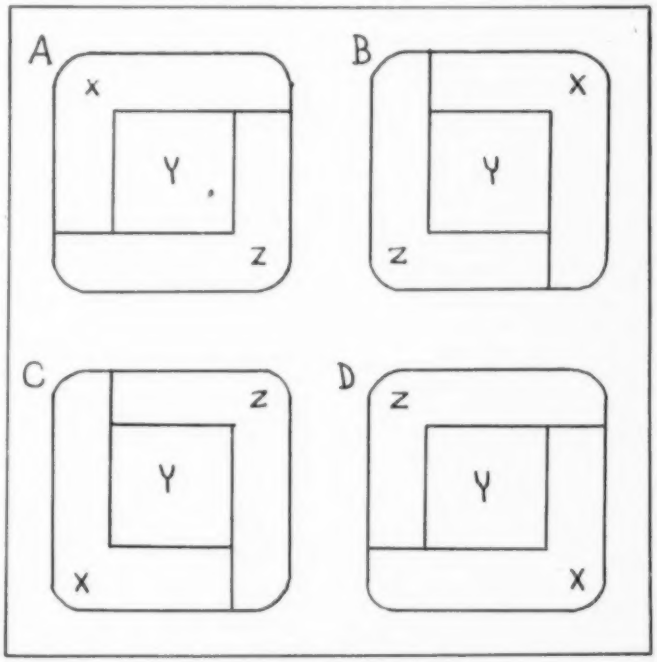


Figure 1—**Pattern of Mold Block**

A, B, C, D = Mold Cavities; X, Y, Z = Areas of Cavity

Mill 1 and Mill 2 stand for two separate millings of plastic powder with plasticizer made on different days. Mold 1 and Mold 2 are two separate moldings made from each milling on the same day each by a different operator.

The locations of Sections A, B, C and D of the mold and of areas X, Y, and Z of the cavities are shown in Figure 1 (Pattern of Mold Block). Specimens were aged for 2 days, 1 week, and 4 weeks and samples from each aging were tested for brittle temperatures by each of two testers,

TABLE 3—Assignment of Degrees of Freedom in Factorial Design for Study of Brittle Temperature of Sheeted Vinyl Plastic

	Degrees of Freedom
Main Conditions	10
Interactions	
First Order	40
Second Order	82
Third Order	91
Fourth Order	52
Fifth Order	12
Total	287

S and J. All test results in the table have been coded. The original readings were in minus degrees Centrigrade.

Instead of performing all 288 runs called for by the complete factorial design, some fraction of the runs, chosen in a planned pattern, may be made, with some loss of information, of course. A considerable degree of understanding of the underlying statistics and of the purpose of the experimentation are required for intelligent choice of the appropriate fractional design. Understanding of at least the terminology in common use is assumed in the following discussion. Some of the considerations involved may be explained by reference to a tabulation of the degrees of freedom available in the full factorial design, Table 3.

One-half replication involves eliminating half the runs, or 144 degrees of freedom. Fortunately, information is lost first on the higher order interactions which would be particularly hard to explain in technical terms, anyway. Beginning with the highest order interaction, it can be determined just how far up Table 3 half-replication will affect information available on interactions. The seriousness of the effects may depend on the availability of an independent estimate of experimental error, the importance of lower order interactions, and possibly other things not easily covered in detail in a brief discussion. With this in mind, it can be said of half replication, in this example, that it would most certainly obscure effects of third and higher order interactions and might affect seriously the ability to identify significant second order interactions. This is not considered to be a detriment, so at least half-replication would be advisable in this instance.

The results of still further reductions in the number of runs may be considered. One-third replication involves eliminating 192 degrees of freedom and would knock out information on second order interactions. One-quarter replication eliminates 216 runs, but first order interactions

TABLE 4—Average Brittle Temperature of Vinyl Plastic for Mold Sections and Aging Periods (Degrees C.)

Sections	C	B	D	A
Av.	-24.41	-25.58	-25.83	-26.33
Aging	2D	1W	4W	
Av.	-25.00	-25.31	-26.31	

could still be tested by a reasonably adequate residual error term. This is probably as small an experiment as would be advisable ordinarily.

However, there can be no objection to performing part of the planned runs and then stopping to see if what has been done is adequate. Quite a lot of information was available on the experimental error involved in brittle temperature testing. Therefore, only a one-sixth replication, indicated by the test results entered in Table 2, was made. The residual error (first order interactions) was so small compared to the independent measurement of error, that it was concluded that first order interactions were non-significant (although not separated by this experiment) and that sufficient data were on hand to test the gross effects of the main conditions. At the 95% significance level, only the section of the mold, and the Aging Period were found to have important effects.

The averages for the four sections and three aging periods are shown below, Table 4. Using a technique devised by Tukey[1], Section C is found to be different from B, D, and A which are indistinguishable among themselves. Also there is a significant overall variation due to aging, which, incidentally, appears to be explained by a direct linear correlation of brittleness with time.

Advantages from all four sources of improvement may be pointed out as resulting from this experiment. There are valid objections to the procedure used but, in fact, results confirmed the previous experience of the laboratory.

Example B

In product development, it is a common practice to compare an unknown or evaluation sample with a standard or control sample prepared at the same time. The purpose of this is to eliminate from the comparison, as far as possible, uncontrolled or uncontrollable variations in both tests due to inconsistencies in the testing methods, weather, or other extraneous conditions. Use of a control chart for the standard material along with a control chart for the development samples provides a rapid method for comparison and relieves many situations where decisions concerning the evaulation sample might be in doubt.

In the comparison of new insecticide formulations against the official test insecticide control, an opportunity for use of this procedure presented itself. In addition to the savings in cost due to fewer samples per formulation, the certainty and rapidity with which decisions were made caused observable improvement in morale of the laboratory.

The construction and use of control charts is so simple and so widely understood that direct reference is made to Figure 2, Control Charts for Insecticide Evaluation. Control on the standard chart means that simultaneous lack of control in the product chart is due to unusually high or low potency in the unknown. On the other hand, lack of control on the standard chart indicates a

[1]Turkey, John. "Separating Means in the Analysis of Variance," *Biometrics*, November 1949.

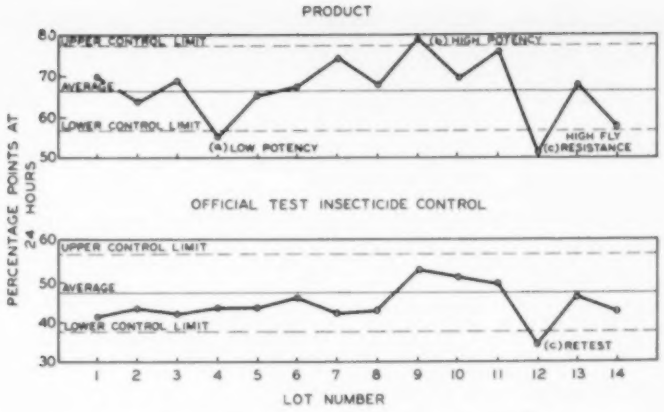


Figure 2—**Control Charts for Insecticide Evaluation**

bad sample or some variation in the test procedure and calls for resampling and testing of both standard and unknown samples. An alternative to use of these two charts is use of a Difference Chart, as described by Grubbs[2].

The problem of measuring improved productivity is a difficult one. Many of the advantages of use of statistics are intangible. Moreover, where the effect of statistics ends and that of good management engineering begins is never clear-cut. In some instances, such as in the last example, the saving in cost of testing is directly measurable. There, the average cost per product sample (or unknown sample) was reduced from $25.00 to $15.00, a reduction of about a third.

Savings greater than this have been claimed in the literature for some research applications of statistics. On several occasions, a point has been made of asking the experimenter to assess the added value of the statistical approach to the total program. As a result, the impression has been gained that an increase in productivity of from 5% to 10% is not an unreasonable goal to expect.

Since, obviously, statistics supplies an added value to experimental work, it will be profitable to take a look at the general areas in which scientists work in order to point out specific areas in which statistics may be called upon.

[2]Grubbs, Frank E., "The Difference Control Chart with an Example of its Use," *Industrial Quality Control*, Vol. 3, No. 1, July, 1946.

AREAS OF RESEARCH ACTIVITY

Hogan[3] mentioned some of the efforts being made currently to define the elements entering into productivity. In particular, Hogan drew upon a report[4] prepared by the American Institute for Research under the sponsorship of the Scientific Personnel Advisory Committee of the American Council on Education.

This report describes the major areas of a scientist's work so that particular behavior affecting productivity may be identified and evaluated. Against this framework, the areas in which statistics will assist in increasing productivity may be described. The general list of areas of research activity are given in Table 5.

[3]Hogan, Ralph M., "Productivity in Research and Development," Science, Nov. 24, 1950, p. 163 et seq.

[4]Critical Requirements for Research Personnel, *American Institute of Research*, Pittsburgh, March, 1949.

TABLE 5—**Areas of Research Activity**

I. Formulating Problems and Hypotheses
II. Planning and Designing the Investigation
III. Conducting the Investigation
IV. Interpreting Research Results
V. Preparing Reports
VI. Administering Research Projects
VII. Accepting Personal Responsibility

PRINCIPLE AREAS WHERE STATISTICS APPLIES

Although the statistician has something to offer in all of these areas, his most important contributions are in areas I, II, IV and V, outlined as follows:

I. Formulating Problems and Hypotheses.
- A. Identifying and exploring problems.
- B. Defining the program (understanding scope).
- C. Setting up hypotheses.

This requires either teamwork between the statistician and the worker in a substantive field or the wedding of statistician-scientist in one individual.

II. Planning and Designing the Investigation.
- A. Collecting background information.
- B. Setting up the assumptions.
- C. Identifying and controlling important variables.

Choosing factors and levels of those factors to be studied and planning to eliminate the effect of others by control, by balancing, or by randomizing.
- D. Developing systematic and inclusive plans.
- E. Developing plans for the use of equipment, materials or techniques.
- F. Anticipating difficulties and alternative outcomes.
- G. Determining number of observations.
- H. Review of preliminary design with all concerned.

IV. Interpreting Research Results.
- A. Evaluating findings.
  Definite conclusions confined to strict deductions from the evidence at hand.
- B. Pointing out Implications of data.

V. Preparing Reports.
Use of tabular and graphic presentation.

CONCLUSION

It has been recognized by many experimenters that time and money spent on experimentation warrants reasonably careful and complete analysis of the data. The important corollary to that point of view is that the intention to spend time and money on analyzing data warrants corresponding care in planning for its collection.

Foundry Quality Control*

A. A. EVANS

International Harvester Company

BY designating this topic "Foundry Quality Control," I do not in any way want to imply that Quality Control in the foundry is basically any different than it is anywhere else. It is still the study and control of variables. The only difference I have been able to establish is that in the foundry we have less control of the variables than in other industries. This lack of control has existed because the present-day foundry stems from an art that, at one time, was covetous and secretive. The advent of mass production forced the change. Foundrymen began to share their knowhow. The transition took place and the foundry almost kept step with other industries. When they started to write books on the foundry, it was found that there were too many diversified ideas. The A.F.S. started its handbook in 1932, and it is still very incomplete. Great strides have been made in metallurgy and foundry engineering but we have still retained this hidden lack of control. It has been overshadowed by the rapid progress. We have grown to accept it as part of foundry practice. It has taken the form of the unwelcome visitor who is tolerated because we do not know how to throw him out.

* Paper presented on the program of the Sixth Annual Convention of ASQC in Syracuse, New York, May, 1952.

Our present knowledge of foundry practice is derived from the trade secrets of melters and molders. Through the long tedious process of trial and error, our present-day foundries have been built, and this inherent lack of control has been incorporated in the practice and accepted as such. For instance, an iron sample may be taken every hour but the result isn't available until the next day. When a shrinkage condition occurs, it sometimes takes weeks to make a correction. The enormous amount of money spent in cleaning and repairing castings is evidence of lack of control.

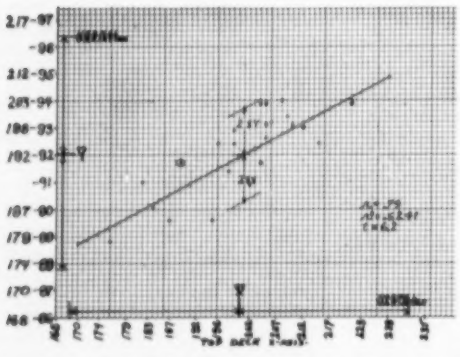
What I am getting at is that we cannot control foundry practice merely by changing a tool setting. We don't have a dial indicator on the cupola that tells us the analysis or the condition of the iron.

To eliminate this lack of control, we have to make functional changes. We have to find and devise methods of control. We have to change our way of thinking in order to eliminate intuitive decisions that have caused so much trouble in the past.

We have exhausted the trial and error method. Many scientific methods are inadequate because you can observe only one variation at a time. Therefore, we must have some method of study that can incorporate a vast amount of variables and control their end result.

Now almost any foundryman can tell you right away that this is impossible. There are just too many variables. They can reel off a list of reasons a mile long — green strength, hot strength, retained strength, grain size, contamination, green compression, permeability, flowability, moisture content, analysis of scrap and pig iron, size of scrap and pig iron, coke size and contamination, charge mix, weight of charge, hot-blast height of coke bed, rate of melt, core hardness, core tensile strength, moisture content, amount of core gasses, analysis of melt, mold hardness, mold finish, rate of pouring and humidity. Believe me, this can go on forever. But the truth is that every one of these are variables affecting the outcome of a casting and quality control is the study and control of such variables. We can therefore conclude that quality control by statistical methods will work in the foundry or any place else where repetitive processes are performed.

It is important that we all realize that the foundry is virgin territory as far as QC is concerned.



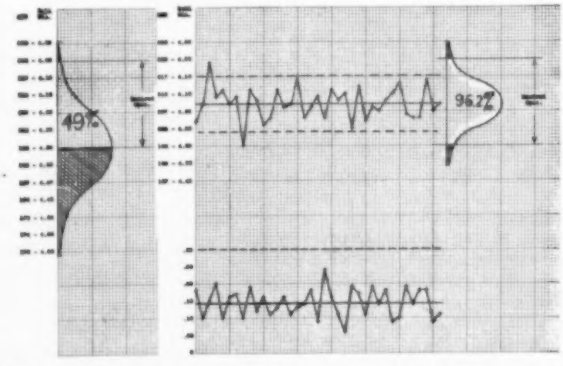
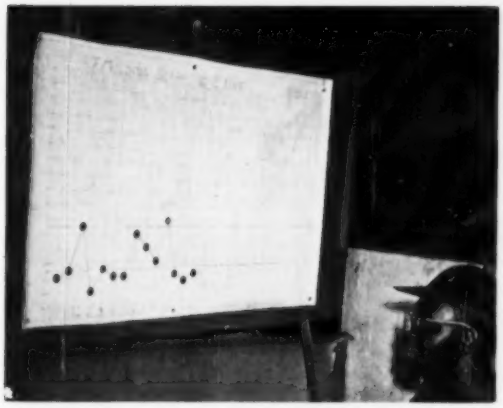


Figure 1—**Correlation Between Cylinder Bore and Top Deck Hardness of Motor Block.** Figure 2—**Histograms and Control Chart of Hardness of Motor Blocks Before and After the Application of SQC**



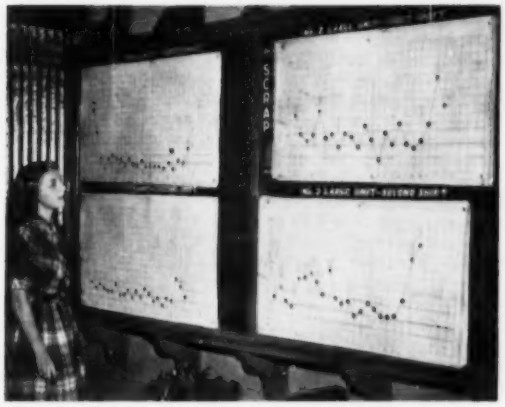


Figure 3—**Percentage of Scrap at the Molding Operation.** Figure 4—**Per-centage of Scrap Charts Located in the Foundry Superintendent's Office**

There are so many questions to be answered. We are attempting to answer these questions through the medium of statistical methods.

A PROBLEM IN HARDNESS CONTROL

As an example, about a year ago we were asked by engineering to maintain a Brinnell hardness of at least 190 in the cylinder bore of an engine block. The hardness specifications for this block are 170 to 223 on the top deck. We had been checking our blocks and knew that we were fairly well within specifications. But this 190 bore hardness had us stumped. We knew that the various sections of the block varied in hardness according to their structure and position in the mold. We also knew that it was fallacious to speak of a hardness of a piece of cast iron. There is too great a variation within one piece. It is necessary, therefore, that we speak of the average hardness of a piece. What we had to know was the relation between the top deck hardness and the bore hardness. The laboratory had its routine hardness checks but we realized that if we wanted an actual controlling factor, our study would have to be made under the adverse conditions in the foundry, not under laboratory conditions where a piece could be surface ground before testing. In the present setup, we had to spot grind freehand before testing. Random blocks were checked for the average top deck hardness and the corresponding average bore hardness. From these we made a correlation study which is summarized in Fig. 1.

Prior to this study, the relationship, if any, between top deck and bore hardness had been doubtful. By applying statistical methods, we established that the relationship is real and constant enough for reliability. From this study we found that the top deck would have to be held above 196 in order to maintain a bore hardness of at least 190.

In conjunction with this correlation we had to run another study to determine the relationship between top deck and the pan rail. We knew that it was the hardest part of the block, so we had to be sure that the pan rail would still be machineable even after increasing the hardness of the block. Since this study gave satisfactory results, specifications were set at 196 and 223. Then all we had to do was to find out how to make blocks within that specification.

The chill test was the only characteristic we could observe, while the metal was in the molten state, that would give an indication of the physical properties of the casting. So a study of the relationship between chill depth and hardness was made. We found that it was necessary to hold the chill between 4.5 and 5.5. This was much higher than the regular run of base iron. Also, alloy conditions would have to be used to maintain this chill. These additions could not be constant but had to be varied according to the chill.

In order to properly control this addition of alloy, we had to develop a chart that would show the chill-test operator just how much alloy to add for a given chill. A chill-test gage was also developed so that the chill could be read in smaller increments of measure. We had been estimating the chill depth to the nearest sixty-fourth of an inch, with a scale calibrated in thirty-seconds. By using this new chill-test gage we were able to read the chill to a quarter of a thirty-second of an inch, or units of .0078 of an inch.

The result of this new method of controlling hardness is shown in the comparative graphical picture on cylinder block hardness (Fig. 2). The histogram on the left shows the process as it was. Almost all of the blocks were within the blueprint specifications which would have to be held in order to maintain the required bore hardness. The chart and histogram at the right of the picture shows the process after the new method of control was installed. Ninety-six percent of all the blocks were within the desired specification.

REDUCTION OF SCRAP

It has generally been the practice in the installation of a QC program to pick only the applications which we were reasonably sure would succeed. At the outset we had no choice of what to start on. We were right in the center of a very critical scrap period; we had to start on that. The first step was to take the regular circulated scrap reports, examine them for the department at fault and present the results in a graphical form. As an

example: The scrap usually caused by the molders was plotted on charts which were hung at the molding units (Fig. 3).

The principal excuse for the high scrap had been sand. However, when the causes were broken down and presented (Fig. 4), it was found that each department shared proportionately in the high scrap. By bringing the facts into the open and presenting them to the men who actually control the scrap, the molders, coremakers and the iron pourers, a very drastic reduction in scrap was accomplished.

In the modern mechanized foundry there is very little opportunity for the skill of the individual molder to be of any great value. The modern foundry is one continuous machine where the individual is part of a hot, sweaty mechanism. His part is monotonous, repetitious and very dull. The type of person who can stand such a job does not have to be a genius, in fact, it is much better if he isn't. There is one thing, however, that is inherent in all men. They are all proud; proud of some accomplishment, their family, their strength. But someplace along the line most of them have lost something; their pride in workmanship. Management has realized this for some time. Various types of incentive plans have been tried, some with relative success, but all lacking in one thing. They failed to give the individual a record of his accomplishment—a record out in the open where everyone could see it.

PUTTING THE CHART AT THE JOB

In one of our first foundry applications of SQC we realized we had the answer. A chart placed on the job to record the man's skill and ability. On one of our crankcase castings where two are made in a mold, patterns number 1 and 2, we were scrapping a considerable number because of a swelled condition on the drag side. A chart of the x and R type was placed on the job and a standard type mold-hardness gage was used to record the hardness of the molds. On this job two men ram the molds alternating each hour. This gave us a splendid opportunity to create competition between them. On our chart we recorded mold hardness in different colors for each man's work. When one man saw his mold hardness was less than the other man's, he would immediately try a different method of ramming to try to beat his fellow worker. This went on for a few days and the mold hardness was brought up and the number of scrap castings became less. At this time we became aware of the fact that the scrap on number 1 pattern had been eliminated and what scrap we were getting was coming from one pattern of each mold. Here we had to change our chart plan and two charts were placed on the job (Fig. 5) to record the hardness of each pattern separately. It was found that the hardness of number 1 pattern side of the mold was much greater on the average than on number 2 side and both men were running the same pattern of variation. Then we knew there was a difference in the operation. It was found that the men were reaching across number 1 pattern which was a long reach and was just a little more awkward in ramming the far side of the mold. This was corrected and the hardness was brought up. Now we have completely eliminated scrap from the swelled condition on this casting and the men are proud of their accomplishment.

Figure 5—**QC Inspector Plotting Mold Hardness Points on an Average and Range Chart**

LICKING A CORE PROBLEM

In the production of most six-cylinder automotive blocks, the heavy barrel core or body core which forms the crankcase and cylinder bores, is made in an open-face four-part core box. A sand slinger is used to fill the box with sand, and the sand is then butt rammed to increase the hardness. The particular barrel core in this example stands rather high, about 20 in. It sits on a flat plate while being baked. Because of the height of the core and its upright position while baking, it is necessary that the core be well-rammed and have considerable green strength to prevent sagging.

Quite often sagged barrel cores would be delivered to the molding unit. When these cores were set in the mold they would shave or crush the green sand causing scrap. If the sag were detected, then the cores could be rubbed to fit. When rubbed cores were used the tendency was to rub them too much, leaving heavy fins on the castings.

This condition of sagged cores had existed for a long time and the correction could not be expected over

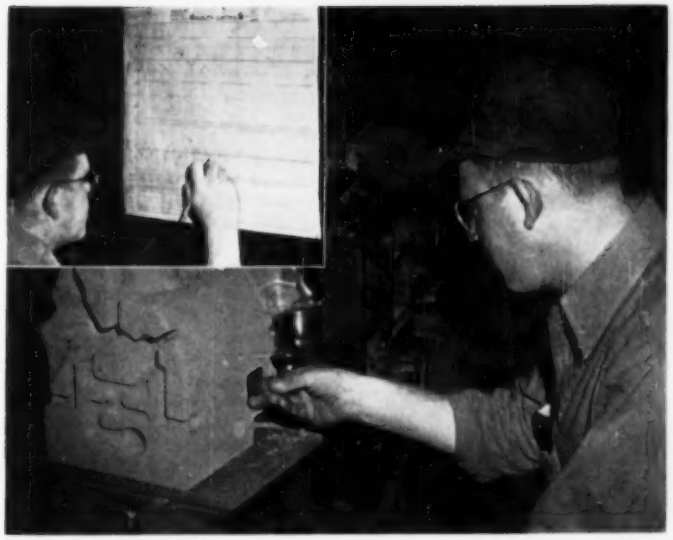


Figure 6—**QC Inspector Checking the Green Strength of a Crankcase Core With Modified Gage.** Inset—**Plotting the Green Strength Points**

night. A statistical study was made of the green core hardness. Some difficulty was experienced in getting reliable readings with a standard mold-hardness gage. The small base plate of the gage was not large enough to prevent the gage from being tipped; it was therefore modified with a 1½x1½ in. base plate as shown in Fig. 6.

After this modification was made a more reasonable pattern of variation was observed. When plotted on an $\bar{x}$ and R chart, the pattern appeared quite normal, but the average, or $\bar{x}$, was rather low—about 43. An $\bar{x}$ and R chart was set up on the job. Fig. 6 also shows the green core hardness being plotted on the chart, which was placed right on the job where the operators could see it. By using the chart as a guide the man who butt rammed the core was able to increase the average hardness to 55. Since this hardness was raised there has been very little scrap caused by sagged cores.

CONCLUSION

For quite a long time foundries have been trying various types of incentive plans to insure the production of quality castings at low cost. Prior to World War II, there was an abundance of skilled coremakers and molders. In most shops where piecework prices were used, the quality was part of the rate. They paid for nothing but good cores or castings. When the war started and skilled help became scarce, the quality standard was lowered in order to meet production schedules. Cores which would have normally been scrap were patched. This patching of cores grew into accepted practice. The amount of casting salvage also increased and an increase in cost followed.

After the war it was found that these precedents which were set during times of emergency had become standard practice. In order to correct this condition, some foundries went so far as to pay extra bonus for good quality of castings and cores.

We believe that we have the answer to this problem. Through our department we have been able to set up a system of checking the quality level of our coremakers and squeezer molders. Each of our coremakers who works on the more delicate and expensive cores, such as water jackets for cylinder blocks and heads, are rated at least twice a day. These ratings are based on the quality of sample groups of cores and plotted on charts right at the coremaker's bench or machine (Fig. 7). A similar system is used for the molders.

We can conclude that, although there is no basic difference between quality control in the foundry and other industries, we do have an inherent lack of control that has been built into foundry practice. This lack of control cannot be eliminated by setting a tool. There is no meter on our cupola that tells us our analysis. We have to make functional changes; find and devise new methods of control. Statistical quality control is the tool that can help us. It has already helped us, but with all the applications that we have made we realize that we have only scratched the surface.

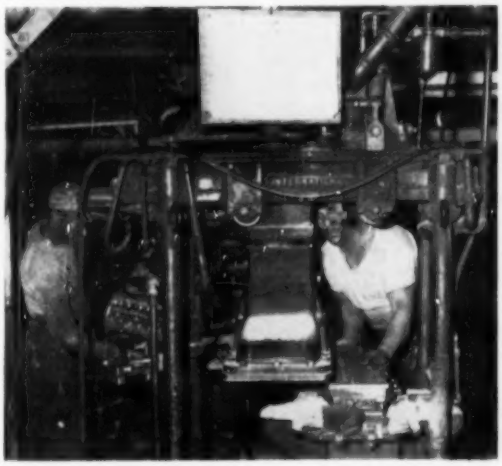


Figure 7—**Control Chart Showing the Coremakers' Percent Efficiency**

Using Statistics to Improve Contact Quality

JOHN L. BEMESDERFER

Fansteel Metallurgical Corporation

THE problems of quality control for routine processes of necessity take up a large portion of any quality control program. Problems of this type are generally solved through use of control charts and acceptance sampling methods. There still remains, however, a large field to be covered by the non-routine methods of conventional statistics—corrrelation, regression, significance tests, and others. The average quality control man is apt to be not too well versed along these lines and so will not enjoy the advantages these tools can give him. Still, their use is not so difficult that any engineer cannot master them with a certain amount of practice. As with any sort of education, we learn best by doing, and it is amazing how a few trials will clarify the use of these methods.

The writer recently was confronted with a quality problem in the manufacture of electrical contacts, making use of tests of significance, correlation, and regression, and the step-by-step solution seems to the writer to be a neat illustration of the use of conventional statistics in working out a knotty industrial problem. It is essentially experimental in nature, as are most problems which yield to these tools.

The writer does not intend to imply that the problem could not have been solved by conventional methods. It very definitely could have been. The contribution of the statistical method to the solution of the problem might be stated as follows:

a. The experimenter is forced to organize the problem and follow through to its solution in an orderly fashion. This adds to the clarity of the problem and makes it much easier for others to understand.
b. The experimenter has a scientific assurance that his solution is a valid one.
c. The solution is found much more efficiently using the statistical method. This is due both to the insistence on organization, plus a narrowing of the band of indecision between a definite yes or no answer. This allows the decision to be made sooner. In many industrial applications this can be extremely important in that many times it is impossible or impractical to obtain more than a fixed amount of data. For example, in the problem this paper deals with, the regression had to be obtained from a total of 17 different parts because no more were available. Using the statistical technique, a reliable answer was obtained from the 17. The writer would hardly have wanted to form any but the vaguest of conclusions from this limited amount of data if he had had only his intuition to aid him.

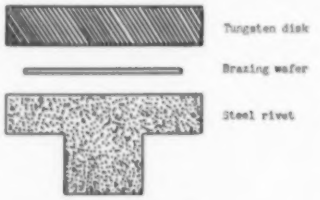


Figure 1

Our problem at Fansteel was in the manufacture of tungsten composite contacts. Certain of our parts had an inordinately large percentage of tungsten disks cracked during the operation of brazing the disks to the steel rivet. Figure 1 will help the reader to visualize the problem. The contacts are brazed together by inserting a thin copper wafer between the tungsten disk and steel rivet, heating the three pieces till the copper melts. Upon cooling, the copper brazes the disk to the rivet. This, however, is now a bimetallic element, and since the coefficient of thermal expansion of steel is much greater than that of tungsten, a stress is set up which tends to bend the tungsten. Being very brittle, the tungsten disk will often crack rather than bend. Typical cracks are shown in the photograph, Figure 2.

Various design changes could cure the difficulty, but these would affect the use of the contact. The only remaining possibility was the character of the tungsten itself, and accordingly a series of experiments were arranged to determine what factors in the material contributed to excessive cracking.

After some consideration, it was decided that two metallurgical factors could cause the situation. For simplicity, let us call these factors A and B. In addition, it was felt that the presence of small edge cracks which do not in themselves impair the contact in use could weaken the disk sufficiently to cause it to crack during brazing. In the case of the first metallurgical factor, Factor A, it was noticed that the percentage of cracked disks seemed to vary between lots despite an *average* similarity with respect to the factor in question. A lot of disks rejected for excessive *variation* was, therefore, selected and two samples which represented the extremes were taken from it. We can call these Type 1, of which we had 105, and Type 2, of which we had 163. These samples were then set up and brazed and afterward inspected for cracks. The results are shown in Table 1.

In order to determine whether this difference is large enough to conclude safely that the Type 1 material generally will result in more cracks, or if the difference is not too large to be attributed to the vagaries of chance ("sampling"), what is perhaps the simplest of all significance tests can be used. This is the u-test for significance of proportions. Other tests, such as a Student-Fisher t-test or Chi-square test, could be used in the form of a contingency table, and the labor of computing would be lessened a little, but their use is

Table 1

	Brazed	Cracked	% Cracked
Type 1	163	72	44.2
Type 2	105	20	19.0

more complicated and is intended primarily for cases where the samples are small. A good book describing such methods is Brownlee's "Industrial Experimentation."

The value u is computed using the formula

$$u = \frac{p_1 - p_2}{\sqrt{\bar{p}\,\bar{q}\,(1/N_1 + 1/N_2)}},$$

where p_1 and p_2 are the proportions defective in samples 1 and 2, $\bar{p}$ is the average proportion defective, $\bar{q} = 1 - \bar{p}$, and N_1 and N_2 are the sample sizes. Substituting the values from Table 1, this becomes

$$u = \frac{\frac{72}{163} - \frac{20}{105}}{\sqrt{\left(\frac{92}{268}\right)\left(\frac{176}{268}\right)\left(\frac{1}{163} + \frac{1}{105}\right)}} = \frac{4300}{1017} = 4.23.$$

In order to interpret the meaning of this u value, it is necessary to understand a little about what is being compared and what assumptions are made in using the test. Consider for a moment the p-chart for fraction (or percent) defective. An average proportion defective is computed from many samples, and this is used as a standard. Control limits are computed from this standard and the size of the sample to be used. Then if the fraction defective of the sample falls outside the 3σ control limits, it is considered ample evidence that the sample represents a lot or process whose fraction defective is not the same as the standard, but is either higher or lower.

The test for proportions is analagous to this test. Here, however, there is no long production run from which to establish a standard. A standard, therefore, has to be determined from the data in the two samples. The mathematician tells us that the most reliable standard is the arithmetic average of the two samples: $\bar{p} = \frac{92}{268}$. Instead of setting up charts, the value u is computed which is indicative of the amount of divergence of two consecutive samples taken from a lot or process whose average is the same as the one we have chosen for a standard. So the question being tested is: "Is it reasonable to assume that we could have obtained a sample of 105 contacts containing 20 cracked disks followed immediately by a sample of 163 contacts containing 72 cracked disks from a process whose average fraction defective is $\frac{92}{268}$, or 36%, if the only source of variation is chance?" If u is less than a certain predetermined amount, our answer is in the affirmative and we may conclude either that Factor A does not affect the number of cracked disks which occur during brazing, or else that our samples were not large enough to yield a significant result. If u is greater than this predetermined value, the answer is in the negative and there is reason to assume that some cause other than chance (in this case, Factor A) was operating to produce the observed excessive variation.

Just what is this "predetermined value" of u, to which the computed u is to be compared? Consider what u really is. It is simply the deviation of the *difference between two proportions* $\left(\frac{72}{163} - \frac{20}{105}\right)$ from zero in terms of the standard deviation (i.e. the number of σ's from zero). Since this value is normally distributed, 3 σ limits could be used as in the case of the control chart. However, this is not generally done with tests of significance for several reasons. In the first place, many of the statistics used are *not* distributed normally, so that 3 σ limits would not represent the same chance for error, which should be kept constant, in all cases. In the second place, 3 σ limits are designed to minimize the possibility of looking for difficulties when there are none, while the experimenter is generally a little more willing to take a chance on saying there is a difference when actually there is none. Third, it will be desirable at times to compare to a single limit in which using 3 σ limits would change the risk by half. Then, too, explanations of results to non-statisticians are not as easy when σ limits are used as when probability of error limits are used. For this reason, tables for significance tests are published in terms of probability of error.

Since u is distributed normally, any table of the normal probability function may be used to find the "predetermined value" of u. We need only to know what "level of significance," or chance of getting a positive answer when a negative is actually the true one, is to be used. In the cases of most statistics for significance tests, tables are published for 1% and 5% significance

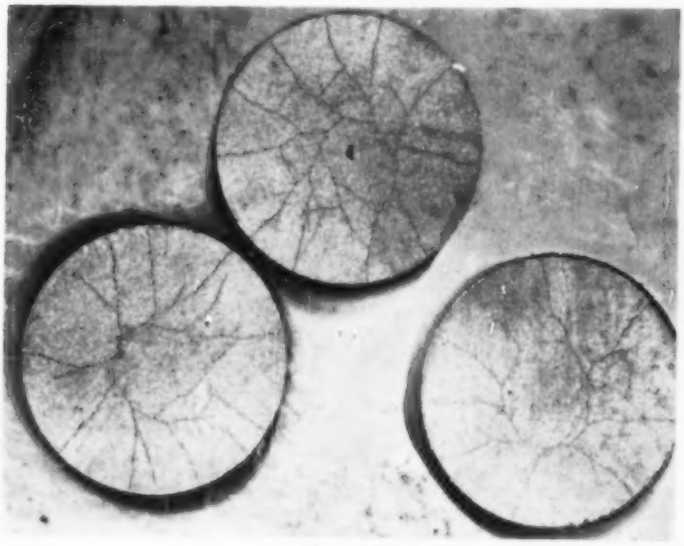


Figure 2

levels. Generally, if the consequences of making the wrong decision are not great, or if other knowledge has already partially given an answer, the experimenter will take the 5% chance. If however, as in our case, no other data are available and a high degree of assurance is desired, a 1% chance is generally taken, and if u falls between the 1% and 5% levels, further experimenting is to be done to eliminate the doubt. Having this "buffer zone" eliminates the possibility of being forced to reject, when u is close to the 1% limit, on what might seem scant evidence.

To get back to our problem, the computed u was +4.23. The u for a significance level of 1% will be found in any normal probability table to be 2.58. Since our u is greater than 2.58, we may conclude that Factor A has an effect on the cracking of the disk.

It is very important that this significance level be chosen *before the experiment is run*. Otherwise one may be tempted, if u should fall between the 1% and 5% points, to use the 5% level, and thus spoil the objectivity of the experiment.

To test whether or not metallurgical Factor B affects the proportion of cracked disks, two samples (we will call them Type 3 and Type 4), which differed only in this factor were cut. These disks were brazed to rivets and inspected for cracks. The results are shown in Table 2.

Table 2

	Brazed	Cracked	% Cracked
Type 3	400	40	10.0
Type 4	400	0	0.0

The test for these results is as follows:

$$u = \frac{\frac{40}{400} - \frac{0}{400}}{\sqrt{\left(\frac{40}{800}\right)\left(\frac{760}{800}\right)\left(\frac{1}{400} + \frac{1}{400}\right)}} = \frac{40}{\sqrt{38}} = +6.5.$$

As was the first test, this is significant at the 1% level, indicating that Factor B is important in the problem.

The third factor, the small side cracks present before brazing, could be investigated in two ways. One is to run a correlation according to the penetration of the cracks, which correlation must then be subjected to a significance test, and the other is to run cracked and uncracked disks at the same time and note the difference. The latter was chosen because of its simplicity, and because the additional information yielded by a correlation was unnecessary.

To execute the experiment, a lot which had been rejected for excessive cracks was chosen. Good sized samples of cracked and uncracked disks were chosen from this lot, were set up, brazed, and inspected. The results were as shown in Table 3.

The computation of u is as follows:

$$u = \frac{\frac{128}{593} - \frac{38}{446}}{\sqrt{\left(\frac{166}{1039}\right)\left(\frac{873}{1039}\right)\left(\frac{1}{593} + \frac{1}{446}\right)}} = \frac{34554}{\sqrt{36888954}} = \frac{34554}{6073} = 5.7.$$

Table 3

	Brazed	Cracked	% Cracked
Not Cracked	446	38	8.5
Cracked	593	128	21.6

This value is, of course, very significant. We then conclude that the presence of side cracks before brazing generally contributes to excessive cracking after brazing.

On the basis of these experiments a method of processing was developed which would minimize the cracking of the tungsten disk. To test this method, another experiment was set up. The purpose of this experiment was not to compare the new process with the old, as one might expect, but rather to find out if the overall process average of the new process is likely to be worse than a given percentage, namely 1%. If a test of significance shows that it probably is better than 1% defective on a 1% significance level, then the new process may be approved with a reasonable degree of safety. Otherwise, the new process should not be approved immediately, but should either be disapproved immediately, or judgment should be suspended until further evidence is gathered.

Now, the particular method of applying the u-test to this situation is much like the three previous tests. There are some differences due to

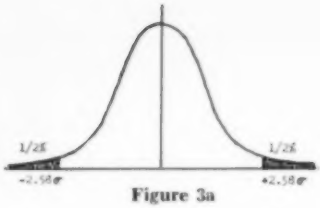


Figure 3a

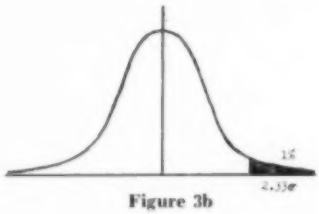


Figure 3b

the fact that in this one a single sample is being compared to an arbitrary standard, and in a single direction. Because of the first difference, the formula for u must be changed to

$$u = \frac{(p - p_1)\sqrt{n_1}}{\sqrt{pq}}$$

where the subscripts refer to sample data and the letters without subscripts refer to the arbitrary or ideal standard.

The second difference gives rise to a change in the 1% limits used for u. Before, they were at 2.58 σ. However, some consideration will lead one to the conclusion that the question being tested here is somewhat different from the one before. Previously, the question was simply, "Is there a difference between the two samples?" The risk that it was desired to control in answering this question was that of saying there is a difference when actually there is none. For this to happen, it must be that the u for the sample chosen is from one of the tails of its distribution (see Figure 3a). In this particular case the error could occur in either of two ways—either sample 1 has more defectives than sample 2, or vice versa. That is, u is either positive or negative. Because of this, half the risk is taken in each tail, and each equal to ½%, so that the total risk is 1%. Thus the limits are chosen at 2.58 σ.

In the present problem, however, the question is, "Is the new process significantly better than 1% defective?" The risk to be controlled is that of saying it is better than 1%

when actually it is not. Now in this case the risk could be lost in only one way—the sample could be significantly better than 1% defective when actually the process is not. If the sample is significantly worse than 1%, the action to be taken is no different than if it should fall in the non-significant zone. That is, the new process is not approved. For this reason, the 1% risk must all be taken in the positive tail of the distribution, and since in a normal distribution, 1% of the population lies above 2.33 σ, the limit is set at $u = +2.33$ (see Figure 3b).

The next problem which arose was one of sample size. Because we were asking for a low risk with respect to high quality, a small sample could not give the assurance required. For example, consider the case of taking a sample of 100 items, and finding no defectives in the sample:

$$u = \frac{.01\sqrt{100}}{\sqrt{.01 \times .99}}$$

$$= \frac{.1}{.0995} = 1.0.$$

In other words, even if no defectives are found in a sample, we cannot say that this sample indicates a process better than 1% defective. Even if we try $n = 900$, we must find 2 or fewer defectives in order to have a significant result. This was still felt to be a slender allowance. The size finally decided upon was 1200, which meant that 4 or fewer defectives in the sample would result in a significant test.

Table 4

X = R	Y = Percent Cracks
.96	.01
1.15	.46
1.17	.36
1.06	.45
1.00	.25
1.53	2.77
2.76	3.14
1.29	.49
1.48	.84
1.14	.02
.84	.00
1.57	1.83
1.02	.00
1.01	.00
1.01	.02
1.67	1.04
1.82	1.36
2.18	1.73
2.13	1.75

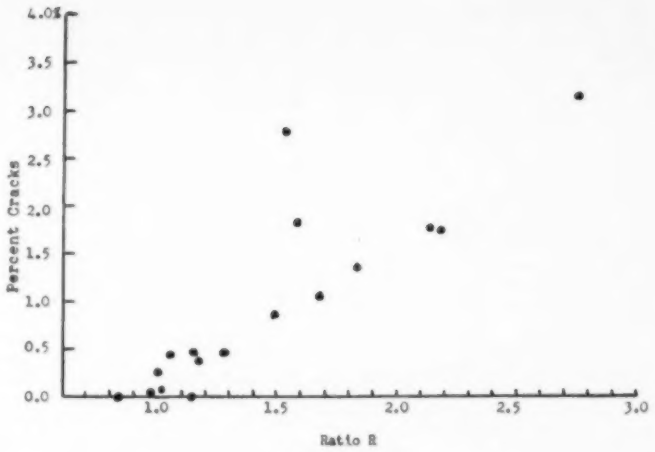


Figure 4

In the sample of 1200 set up and brazed, only 3 were found to be cracked. Thus

$$u = \frac{\left(.01 - \frac{3}{1200}\right)\sqrt{1200}}{\sqrt{(.01)\ (.99)}}$$

$$= \frac{.0075 \times 34.6}{.0995} = 2.61.$$

Since this value is significant, we then conclude that our new process is better than the 1% standard it is desired to maintain.

The particular contact on which this material was tested had previously run about 7% defective, so that about 7% of the manufacturing cost was saved on scrap parts alone, not to mention the saving on the cost of culling out the scrap at final inspection.

After the new process had demonstrated its value in production for a suitable length of time, the problem arose as to what contacts would require new process disks, which are somewhat more expensive to manufacture, and which ones should continue to use the old process disks. For a time it was sufficient to change those parts with poor quality records. After a time, however, the engineering department asked for a method by which it could determine from the design of the contact which tungsten should be used. After trying various combinations involving rivet and disk dimensions, a ratio R was decided upon which the engineering department could use to determine before the contact was made whether old or new process tungsten should be used.

The method of making this choice illustrates another statistical technique which is useful in many industrial situations where both characteristics, called the independent and dependent, are measured as variables.

The first step is to measure the extent of the relationship between these two variables. Such a measure is given by the correlation coefficient (r). Before using the method, it would be well to explain what this r means.

A number of contacts of different sizes and shapes was taken, the ratio R was computed, and the percentage of cracked disks was determined from records. The results are shown in Table 4.

It is always a help to look at a "picture" of the data before going on to compute the correlation coefficient. The picture used for correlation data is called a "scatter diagram" (Figure 4), a plot of the data with the independent variable usually along the horizontal axis.

From the scatter diagram it is immediately evident that all of the points seem to be along a straight line with the exception of two. These two were investigated and unusual causes of excessive cracking were found. Therefore, these two were not considered in determining the extent of the relationship. *This step should always be taken with care*

and is valid only if the experimenter is certain that an unusual reason is present.

The data in this case roughly define a straight line, and so the methods of linear correlation may be used. It could well be that the points would seem to scatter without much rhyme or reason, or will be on a curve rather than a straight line. The first situation indicates that there is no great degree of relationship, and it would be a waste of time to go into the mathematical aspects of correlation. The second indicates that the relationship is non-linear, which may be treated by methods to be found in most good statistics texts.

The correlation coefficient can be defined most simply as a statistical measure of the strength of the linear relationship between two variables. This is not the most accurate definition, but is good enough for the present purpose. Notice the definition merely says "relationship." This should not be construed as meaning dependence of one factor on the other. To illustrate this difference, one may point to such strange results as the high correlation between total annual teacher's salaries and liquor consumption in the United States. Certainly the teachers don't drink a major portion of the liquor consumed, but both of these variables depend directly upon a third, namely the economic condition of the country as a whole.

Another pair of variables which produced a high correlation is the number of men at a certain U. S. college and the annual birth rate in India. This correlation obviously does not make sense, but points out very emphatically the important fact that *correlation coefficients* also obey laws of chance.

Thus, there is a very real danger of concluding that a relationship does exist between two variables when actually there is none, or of concluding that a dependence exists when there is simply a relationship. The first of these dangers can be minimized, but not entirely eliminated, by using a significance test for the correlation coefficient. The second must, by its very nature, rely on the technical knowledge of the user.

In most situations, the letters X and Y are used to designate the independent and dependent variables respectively. To coincide with this terminology, the ratio R referred to above will become X, and the percentage of cracked disks will be Y.

A general formula for computing the correlation coefficient r is

$$r = \frac{N\Sigma XY - \Sigma X \Sigma Y}{\sqrt{[N\Sigma X^2 - (\Sigma X)^2][N\Sigma Y^2 - (\Sigma Y)^2]}}$$

where N = the number of samples (17 in the present case); ΣXY, the sum obtained by multiplying each X by the corresponding Y and adding these products; $\Sigma X \Sigma Y$, the product obtained by first adding the X's and Y's separately and then multiplying these sums; ΣX^2, the sum of the squares of the X's; and ΣY^2, the sum of the squares of the Y's.

A form for routine computing can be very helpful by saving labor and reducing the chances of error. Table 5 illustrates a simple form which can be used in this particular problem. From this table one can easily obtain the factors needed for the correlation coefficient as well as those necessary for the regression computations which follow. For the present problem we have:

$$r = \frac{+125.3}{\sqrt{79.1 \times 214.9}} = \frac{+125.3}{\sqrt{17000}}$$

$$= \frac{+125.3}{130.4} = +.961.$$

The correlation coefficient will equal +1.00 if the points all lie exactly on a straight line sloping upward as we go to the right, or -1.00 if the line should slope downward. Of course, such a situation is never found in industrial experiments, so we generally obtain a value somewhat smaller than 1.00. A value of zero indicates that no linear relation exists between the two sets of measurements. This situation is never met exactly, either.

Is this value of +.961 for the correlation coefficient close enough to 1.00 to be considered significant? It certainly seems to be, but the correlation coefficient is quite deceptive at times so that in almost every case the user would do well to check its significance. The following example will illustrate this point. Five students in a college classroom were asked their school telephone numbers and their house numbers at home. A correlation was run on these data and the coefficient was found to be +.95. This surely looks as if it must be significant. However, when tested for significance it was found that for a sample of 5 this value is not too unusual, although it does push the .01 probability limit, even though the populations sampled are not correlated.

The significance test for correlation coefficients is somewhat different from the one used in the previous problems. The distribution of

Table 5

Sample No.	Percent Cracks Y	R = X	Y^2	XY	X^2
1	.01	.96	.0001	.0096	.9025
2	.46	1.15	.2116	.5290	1.3225
3	.36	1.17	.1296	.4212	1.3689
4	.45	1.06	.2025	.4770	1.1236
5	.25	1.00	.0625	.2500	1.0000
6	3.14	2.76	9.8596	8.6664	7.6176
7	.49	1.29	.2401	.6321	1.6641
8	.84	1.48	.7056	1.2432	2.1904
9	.02	1.14	.0004	.0228	1.2996
10	.00	.84	.0000	.0000	.7056
11	.00	1.02	.0000	.0000	1.0404
12	.00	1.01	.0000	.0000	1.0201
13	.02	1.01	.0004	.0202	1.0201
14	1.04	1.67	1.0816	1.7368	2.7889
15	1.36	1.82	1.8496	2.4752	3.3124
16	1.73	2.18	2.9929	3.7714	4.7524
17	1.75	2.13	3.6625	3.7275	4.5369
Σ	11.92	23.69	20.9990	23.9824	37.6660

$N = 17$
$N\Sigma X^2 = 640.3$
$N\Sigma Y^2 = 357.0$
$(\Sigma X)^2 = 561.2$
$(\Sigma Y)^2 = 142.1$

$N\Sigma XY = 407.7$
$\Sigma X \Sigma Y = 282.4$
$N\Sigma X^2 - (\Sigma X)^2 = 79.1$
$N\Sigma Y^2 - (\Sigma Y)^2 = 214.9$
$N\Sigma XY - \Sigma X \Sigma Y = 125.3$

coefficients for small samples (less than 30) is not normal, but follows the Student-Fisher t distribution. This means that one has to use a special table based upon Student's distribution for various sample sizes. The sample size is not denoted directly in these tables, but is contained in the concept of "degrees of freedom." The meaning of this term is beyond the scope of this article. Suffice to say that for the coefficient of correlation the number of degrees of freedom is 2 less than the number of pairs. Thus for this problem there are 17 - 2 or 15 degrees of freedom.

The formula for t for the coefficient of correlation is

$$t = \frac{r\sqrt{N-2}}{\sqrt{1-r^2}}$$

Substituting in this formula

$$t = \frac{.961\sqrt{15}}{\sqrt{1-.961^2}}$$

$$= \frac{.961 \times 3.87}{.276} = 13.5.$$

Most statistics textbooks have t tables. For 15 degrees of freedom and a 1% significance level, t is found to be 2.95. Since the t of the observed values is greater than this value, the correlation coefficient is judged to be significant and so it is concluded that a linear relationship exists between the ratio R and the number of cracked disks occurring during brazing.

We now know that the percentage of cracked disks is a linear function of the ratio R; we would like to know (a) what the relation is, (b) how reliable it is, and (c) at what value of R the old process produces more cracks than can be tolerated in production.

To solve these problems, the first step will be to find the equation of the straight line which best fits the data. Since the data do not lie exactly on this line, the next step will be to establish a band on each side of the line which will include the data. The third and final step will be to find the value of R at which the upper limit of this band exceeds 1%, which is as high a percent defective as we feel the process should be allowed to attain even under extreme circumstances.

The equation of any straight line is of the form $Y = a + bX$, where X and Y are variable quantities, such as the ratio R and the percentage of cracked disks, and a and b are arbitrary constants. The problem then is to find an a and b from the observed values of X and Y. The statistician tells us to set up a pair of simultaneous equations and solve them for a and b. One of these equations can be set up quite easily: since each X and each Y will approximately satisfy the equation, then their averages should be an excellent solution:

$$\bar{Y} = a + b\bar{X}$$

or, to write it in a more usable form:

$$\Sigma Y = Na + b\Sigma X.$$

The second of these equations is not quite so obvious, but it can be made to seem reasonable. If each point X_1, Y_1; X_2, Y_2; etc. is to satisfy the equation, the entire equation may be multiplied by the corresponding X without destroying the equality. These may then be added to form a "weighted average" equation:

$$X_1Y_1 = aX_1 + bX_1^2$$
$$X_2Y_2 = aX_2 + bX_2^2$$
$$\cdots\cdots\cdots$$
$$\cdots\cdots\cdots$$
$$\Sigma XY = a\Sigma X + b\Sigma X^2$$

The solutions to these equations are:

$$a = \frac{\Sigma X^2 \Sigma Y - \Sigma XY \Sigma X}{N\Sigma X^2 - (\Sigma X)^2},$$

$$b = \frac{N\Sigma XY - \Sigma X\Sigma Y}{N\Sigma X^2 - (\Sigma X)^2},$$

so a and b may be computed from these formulas, using values of X and Y obtained from observed data.

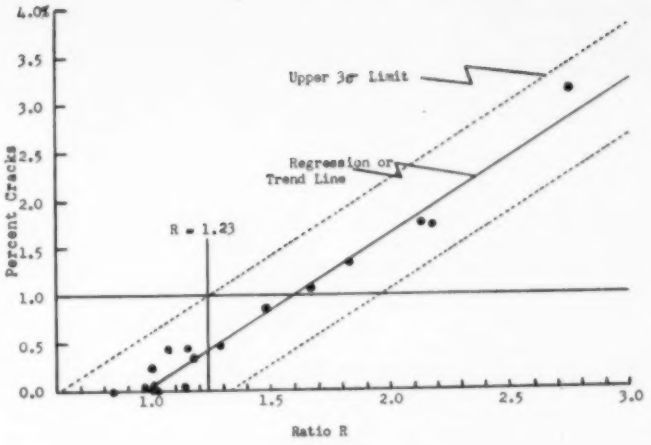


Figure 5

The above is a sample explanation of the derivation of these equations. The actual method of obtaining these "average equations" (normal equations, the mathematician calls them) involves more complex mathematics and the solution is actually the line which makes the sum of the squares of the vertical distances from all the points to the line a minimum. Thus one will often hear these statistical methods of correlation and regression referred to as "least squares methods." For us the above explanation is sufficient to illustrate that we have obtained the straight line which best fits the observed data.

It will be noticed (see Table 5) that the factors used in computing a and b are almost the same as those used in computing the correlation coefficient. This is because there is a close connection between the ideas of correlation and regression. From the factors given in Table 5 we may compute a and b:

$$a = \frac{449.0 - 568.1}{79.1} = -1.51,$$

$$b = \frac{125.3}{79.1} = 1.58.$$

The regression line for this problem is then

$$Y = -1.51 + 1.58X.$$

The second step is to establish a band on each side of the line which will include the data. This can be done by using the "standard error of estimate." This is the standard deviation, S_y, of the vertical distances from the observed points to

the regression line, ("errors") and is given by the formula

$$S_Y = \sigma_Y \sqrt{1 - r^2}.$$

In this problem, the solution is

$$S_Y = \frac{\sqrt{214.9}\,(.276)}{17} = \frac{(14.66)\,(.276)}{17} = .238.$$

A $2.4S_Y$ band was used on each side of the line for the present problem. This meant finding the equations of the lines $2.4S_Y$ (=.57) above the best-fitting line and $2.4S_Y$ below it. To find these, we need only to add and subtract $2.4S_Y$ to the equation of the regression line:

$$Y_U = -.151 + 1.58X + .57$$

(a) $Y_U = -.94 + 1.58X;$

$$Y_L = -1.51 + 1.58X - .57$$

(b) $Y_L = -2.08 + 1.58X.$

To accomplish the third step mentioned above, it is only necessary to substitute the value of .01 (1%) in equation (a). This is the point at which the upper limit line crosses the 1% defective line (see Figure 5). Solving for X gives the limiting value of the ratio R above which disks made by the old process may crack excessively:

$$1.00 = -.94 + 1.58X$$

$$X = \frac{1.94}{1.58} = 1.23.$$

In practice, the engineering department uses 1.25 as the point at which the new (and somewhat more expensive) process is recommended on a given contact design.

How to Detect the Type of an Assignable Cause

Part II. Procedure When Probable Cause Is Unknown

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Editor's Note

This is Part II of the article prepared by the author for the Third Midwest Quality Control Conference held in Chicago on November 4 and 5, 1948. Part I appears in the last issue of IQC. The follow-up in this second part suggests procedures for detecting the type of an assignable cause when the cause is unknown.

PRELIMINARY CONSIDERATIONS

In Part I, we assumed that we knew the type of cause for which evidence might be present in the data. Several methods by which such evidence might be measured were suggested together with an order for making use of them. So far, we have not shown how these methods may be classified. That some similarity exists among them is evident in our reference to control charts for certain ones and to run charts for others. To make this clearer, all the information in Part I has been combined in Table I. Five general classifications of statistical tests are shown—control charts, extreme differences, runs, nonparametric association, and analysis of variance. At least two subgroups are shown for each. In all, 17 ways of measuring the evidence for the various types of trouble are indicated. The fact that four or more may be used to measure evidence for each of the five types of trouble discussed in Part I means that these 17 are not all independent.

In view of this, it is at least theoretically possible to select from these 17 methods the five that would be expected to provide the most positive identification, one by one, of the five listed types of trouble. Keeping in mind simplicity of use as well as ability to identify, a reasonable choice would appear to be:

1. p_k for gross error
2. Runs in x above and below for shift in average.
3. Runs in R above and below for shift in variability
4. Runs in x up and down for a trend
5. Runs in x up and down for a cycle

Experience has shown that when one of these methods suggests trouble, it is usually associated with the type indicated. Conversely, however, it is possible to have trouble present without its being detected by what would ordinarily be the appropriate method. For this reason, it is desirable to add something to help detect these cases.

Two alternatives are suggested:

a. Apply all of the methods discussed in Part I and listed in Table I, or
b. Add one or two other methods to the five selected above that would be the most useful in analyzing trouble.

Both alternatives have advantages. The first provides several methods for each type of assignable cause so that it is easier to decide what type of trouble is present. The numbers in each line of Table I indicate an order in which the tests for each type of assignable cause might be made. For the second alternative, the suggested additions are the serial quadrant sum to help identify cycles and analysis of variance to provide a quantitative measure of factor effects when replication shows statistical control. To apply analysis of variance, the data must first be examined for statistical control with respect to the replicated factor. If such control does not exist, measures associated with analysis of variance may be invalid.

PATTERNS TO LOOK FOR

In the preceding section, selections were made from the results of Part I that seemed to give what we wanted. This was done on the basis that we, as engineers, have associated certain patterns that we have encountered in the past as having occurred along with specific types of detectable causes. It is customary for some engineers to look for these patterns in each set of data they examine. This, in a sense, is a crude visual test of the data. It usually suggests the statistical measure that is apt to confirm suspicion concerning the presence of an assignable cause. In fact, it may suggest several measures,

each of which may contribute something to help identify the cause.

Before going farther, perhaps it will be worthwhile to state some conclusions based on engineering experience that serve as the primary assumptions in examining each new set of data:

1. In general, all engineering data show evidence of the presence of assignable causes.
2. In general, engineering data that meet statistical requirements for a state of statistical control are obtained only after eliminating one or more assignable causes.

Each of these statements is introduced by the qualification, "In general." How serious is this? Well, it is theoretically possible that a set of engineering data might be obtained sometime, somewhere, and by somebody that will meet the requirements for statistical control without having to eliminate even one assignable cause. I have yet to hear, however, of a single case where these requirements have been met without first eliminating some assignable cause.

With this background of experience, we may conclude that the engineer is justified in his assumptions concerning the presence of assignable causes. It also seems reasonable that he should look for the patterns which he has associated with assignable causes in the past. Depending then on the observed pattern, specific methods of statistical investigation are suggested.

PATTERNS AND STATISTICAL MEASURES

The engineer would also like assurance that the statistical measure chosen is a good measure of the pattern suggested visually. It need not be the best measure, but it should be reliable. Other desirable characteristics of a good measure are that it shall be easy to compute, easy to explain, and readily presented in graphical form. These characteristics may be summed up in the single word—simple. When statistical ideas are to be used in discussing engineering matters with other engineers who are not familiar with them, there is a great advantage in being able to talk in terms they understand. This may be accomplished by picking a group of patterns or pictures similar to those considered in Part I and some of the simplest methods by which these patterns may be measured. The engineer is familiar with blunders, shifts in level, and the like, even though he may not have what could be considered an adequate measure of them. Experience indicates that most engineers find it easier to grasp the meaning of runs and quadrant sums than to understand control charts. Analysis of variance methods, however, seem mystical even to the statistician.

Although the patterns discussed here are the ones that have been found useful in studying research and development data, we must always be on the lookout for others.

One of the most perplexing patterns I have seen was that provided by wear measurements on 204 consecutive lengths of cotton yarn. The engineer who had obtained them was very much pleased to report that he had made control charts for averages and ranges of samples of four and had found all averages and ranges well within their respective control limits. The longest run on either side of the median was only of length, eight. The probability that a random arrangement of the 204 measurements would have such a run was close to 0.5.

Questioning established that the pedigree of the yarn was not good—that is, the engineer was reasonably certain that the manufacturer had not taken any special precautions to see that the product was uniform. At any rate, he was certain that the manufacturer had not installed statistical quality control procedures for finding and eliminating assignable causes. Thus, the only assumption worth making was that there must be some evidence for lack of statistical control in the data.

When the data were plotted in the order that the lengths were cut from the spool of yarn, it was easy to locate a section where all observed values for 30 consecutive lengths were either in the uppermost third or in the lowest third of the distribution of the 204 measurements. Not a single observation of the 30 was in the middle third. Since such a group of 30 can occur in 175 possible locations in the set of 204 observations, it is easily seen that the probability that a random arrangement of the 204 would contain such a group is at most $175(2/3)^{30}$ or 1 in 1000.

TABLE I. **Tests for Locating and Identifying Specific Types of Assignable Causes**

Type of Assignable Cause	Control Charts				Extreme Differences		Runs Above and Below				Runs Up and Down		Nonparametric Association		Analysis of Variance		
	$\bar{x}$	R	σ	ν	P_Δ	P(g)	$\tilde{x}$	x	R	ν	$\bar{x}$	x	Quadrant Sum	Serial Quadrant Sum	Regression Analysis	Serial Correlation	Other Analysis of Variance
Gross Error (Blunder)	1	2	..	..	3	4	..	..	..	..	..	..	..	..	..	..	..
Shift in Average	1	..	..	..	..	..	2	3	..	..	..	..	..	..	..	..	4
Shift in Variability	..	1	2	..	..	..	..	..	3	..	..	..	..	..	..	..	4
Slow Fluctuation (Trend)	1	..	..	..	..	..	2	3	..	..	5	..	..	..	..	..	4
Fast Fluctuation (Cycle)	..	1	2	..	..	..	..	..	..	3	..	6	..	5	..	7	4
Combination a. Production	1	2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
b. Research	..	..	..	..	1	..	..	2	3	..	4	5	..	6	..	..	7
Covariation	1	..	..	..	..	..	2	3	..	..	..	..	4	..	5	..	..

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This was taken as confirming evidence that an assignable cause was in fact present. As soon as this pattern was recognized, the engineer knew the type of cause to look for.

In many cases, an exact statistical measure for an observed pattern may not have been computed. Sometimes, however, a transformation to a plot for which the pattern measure is known is possible. In either of these cases, a mathematical statistician may be able to make a crude probability estimate that will be sufficient for the purpose of corroborating the likely occurrence of the suspected trouble.

CORROBORATIVE MEASURES

By listing more than one way to measure a given pattern here, the idea is being suggested that we may wish additional evidence that trouble is present or that we may wish more information concerning the kind of trouble that is present. Consider the two measures of variability—range and standard deviation. These may or may not both be outside control limits for identical samples. If an assignable cause changes the value of one observation and is such that it increases the range of a sample of four, it will increase the standard deviation also, but the converse is not necessarily true. This suggests that use might be made of a plot of range versus standard deviation for samples of four to distinguish between variability of these two types. The practical significance of such a difference is a reasonable question for investigation by the committee proposed in Part I. There is also an important difference between the use of the range and the use of the standard deviation, in the presence of an infrequently occurring assignable cause, in the probable effect of the cause on the average of each of the measures. This difference occurs because the range is a linear measure and the standard deviation is determined from the average squared deviation. For this reason, a range control chart will often show points out of control when the standard deviation control chart does not. (This will not be true when the assignable cause occurs frequently.) This means that the range control chart is more efficient in a practical sense for catching this type of trouble. Mention was made in Part I of the possible use of the median range for various purposes and of establishing its relative usefulness for assisting in catching trouble. It is now clear that in many research situations, the use of the median range leads to earlier identification of trouble. In some cases it does not. This is an added reason for looking both ways.

The engineer in his work must differentiate between the use of "efficient" in the sense, "efficient for catching trouble," and the use of "efficient" in mathematical statistics. In the latter case, the mathematical statistician finds that, when no trouble is present, a given precision in the standard deviation may be obtained with a smaller sample size by using standard deviation as a measure than by using range. This assumes that we are primarily interested in estimating the standard deviation for the process and that we have reached a state of statistical control. In engineering work, these assumptions will not be worth making until it has been demonstrated that a state of statistical quality control does in fact exist. In this discussion, we are interested primarily in reaching such a state.

A dissertation on the ways in which the selected measures provide information of a corroborative nature is very much beyond the scope of this article. It is clear from the example given that no two measures are equally good for detecting the same type of assignable variation. Each is apt to include some cases that we might wish to exclude or vice versa. However, if two or more measures indicate that trouble is present, we may be reasonably certain that the kind of trouble that is commonly detected by both is present. The probability measure for such occurrence in a random sample would, of course, be no greater than the smaller of the probabilities for the two measures taken separately.

SITUATIONS FOR DETECTING TROUBLE

Having derived a systematic procedure for detecting trouble, it is now worth while to consider when, where, and how it should be used. What situations are commonly encountered by the engineer and what measures should be used in these situations as a basis for looking for trouble? Most of us distinguish between two quite different situations that we may designate as associated with manufacture and production on the one hand or with research and development on the other. The first is concerned with making things; the second with getting ready to make things. One is related to operations that are repeated again and again; the other is related to doing something new, to false starts, stops, and changes.

In the case of production, it is important that procedures be adopted that do not interfere in any important way with the actual process of turning out units of product, unless the indicated deviation in product quality is "economically" worth finding. How is such a criterion established?

Many manufacturers maintain lists of the deviations that they have found in product quality in the past together with the causes that produced them and the inspection procedures that are most apt to disclose their presence. If the process is to be an economical one, it is necessary to take steps to see that such deviations do not occur too often. At the other extreme, it might not be considered economical to take action every time such a deviation is found. This situation leads directly to Shewhart's concept of "economic control of quality of a manufactured product." In the case where quality is measured as a variable, the distinction between good and bad is apt to be less exact. The product may be usable regardless of the measured value of each unit but the probable life performance of each unit may be related to its measured value. Many products are subject to judments of quality determined in this way. There exists a desired value which may be taken as the expected average. Often, it is selected by the engineer while the product is being developed. After experience with manufacture, an average level for the process itself may be established. More will be said about establishing this level in a later section. Having established a level, it then becomes the duty of the production engineer to see that this level is maintained in the product within economic limits. It is the common experience among quality control engineers that the use of control charts for averages and ranges is sufficient for this purpose (Table I).

It seems reasonable, therefore, that the production engineer should not make use of the techniques discussed in this paper as part of the routine work of maintaining a controlled process. Some may argue that if he

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does not use them, he will not have a controlled process. It is agreed that he might discover causes of lack of control a little earlier if he used them. The major point, however, relates to his objective which is economic control of quality. Many minor causes of lack of control are not of economic importance and should be disregarded when we are dealing with production. What we do wish to detect are changes in level or variability that change the serviceability of the product in a way that will be important to the consumer of the product. In an economic process, it has been demonstrated time and again that this may be accomplished through the use of control charts for average and range without using other means.

In the case of research or development, the objective is not the same as in production. The engineer is not satisfied in carrying out his researches unless he can identify and measure the effect of each element that must be controlled to produce minimum variation in the measure that he is making. For this reason, he looks for the patterns in his data that he has associated with particular types of variation in the past. It is for his work that the procedures outlined here have been found useful. In some cases, his information may be so sketchy that he does not know or he may not realize that he has a basis for knowing what type of assignable cause to look for. It is part of the job of the engineering statistician to help the engineer resolve this dilemma. Where he has special reason to suspect particular types, Table I shows the measures that may be most useful. But if he does not have such special information and does not see any pattern in his data that would suggest a particular type of cause, the table also suggests a set of measures that should be helpful in analyzing his data to identify the type of assignable cause that may be present.

COVARIATION

In the foregoing, we have drawn attention to what may be considered repetitions of a single measurement. These is also the case where more than one kind of measurement is made on each unit. Much, if not all, engineering work is of this type. Before going farther with this case, it must first be assumed that each of the kinds of measurement has met conditions for control. In other words, the procedures suggested so far in this article have been applied and the data for each kind of measurement meet the requirements for control; that is, they do not indicate the presence of assignable causes. Having established this, we may proceed to consider covariation.

In the simplest case, two characteristics, say x and y, are measured on each consecutive unit of a product or other system of causes. Both x and y when considered *independently* appear to have come from a controlled process. Examination of this condition is sometimes overlooked, and if so, may lead to nonsense correlation. Another important thing to keep in mind is that there should be some physical reason for believing that one measurement is dependent in some way on the other. There is also the question of which one is dependent and which is independent. Is x in a physical sense dependent on y or y on x? If y is the characteristic that is the overall objective, it is often assumed that y is dependent on x, particularly if by closer control of x, the variability in y can be reduced. For some purposes, it is also necessary to take into account the precision of repeat measurements on both x and y.

The simplest technique for detecting covariation is a control chart for the sample averages of the dependent variable for uniform intervals in the independent variable. Other techniques (Table I) include runs above and below for these averages and also for individual values, the quadrant sum, and regression analysis. Control charts, runs, and the quadrant sum are simple in concept and often prove easy to explain to others who have had little or no experience with statistical analysis. Each provides a measure that is useful in attempting to answer the engineering question: "If a better method can be found that will produce less variation in x, will the variation in y be reduced?" The answer to this question is apt to be important in the case where the correlation is low as well as where the correlation is high. The matter of importance may be related more to what can be done in reducing the variation in y than it is to the amount of the correlation. For this reason, the concepts and methods discussed here are particularly useful in research and development work where it must be decided whether it is worthwhile to consider or to develop new techniques for controlling the x on which it is presumed that the y will depend.

SETTING CONTROL LEVELS AND TOLERANCE LIMITS

Based on his research and development studies, it is possible for the engineer to select average values for each of the characteristics that are to be measured for the product. It is these values that represent the intent of design. They are values established from his development studies as being the ones necessary to give a satisfactory product. As the design goes into production, some of the values desired by the engineer are apt not to be met. At this stage, production research takes over to establish the average values that will apply as quality levels to be maintained by the process that has been established. These levels may or may not be identical with those set by the development engineer. If, as is frequently the case, they are not, he must agree to them as being sufficiently close to what he selected and as being satisfactory for the kind of product he intended.

Capability with respect to product variability is the special field of production research. It is established for each of the measured characteristics during the period while production is being started. It is most important at the beginning to use methods of the type discussed here to locate and identify as soon as possible the various assignable causes that have to be considered for the product. If this preliminary examination is properly carried out, then when full production is established, greater reliance may be placed on the control charts for averages and ranges alone. It is during initial production that the major causes of trouble are determined and steps taken to see that they are brought and kept under control.

Having reached a state of statistical quality control, the production research engineer is desirous of setting tolerance limits for his product —tolerance limits that are statistically appropriate for the production process. One method of setting such limits is to place them at three times the standard deviation on either side of the average. The latest and most complete results* on this

*A. H. Bowker, "Tolerance limits for normal distributions." Chapter 2 of *Selected Techniques of Statistical Analysis*, McGraw-Hill, 1947.

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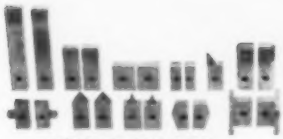

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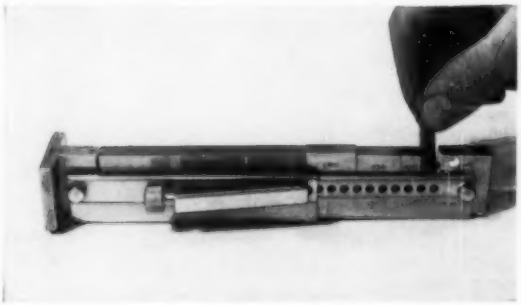

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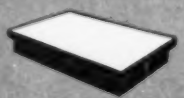

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point indicate that, "if the sampling is from a normal universe," tolerance limits established in this way for a sample of 140 will include 99% of the universe 99% of the time. To meet the "if" clause in the last sentence is often extremely difficult if not impossible in engineering work. As a minimum it means that the production research man has obtained a set of data that is apparently free from the types of assignable causes discussed in this article. However, this may not be enough because normal universes are rare in industrial work. Therefore, to be on the safe side, it is usually preferred to use samples of the order of 1000 to establish tolerance limits, particularly if they are to be taken as specification limits to be met in production and inspection. In order to make such limits effective, it is necessary in production to use control limits on the averages and ranges of consecutive samples as a basis for corrective action to see that the process remains in statistical control.

SUMMARY OF PART II

The processes of analysis that have been described are designed to uncover in an orderly fashion evidence for the presence of assignable causes that might elude the engineer or scientist. If such a cause had been suspected, provision might have been made in the experiment to measure its effect. Discussion with the engineering statistician often suggests such causes that might ordinarily be overlooked. Hence, it is helpful for the engineer and statistician to work together as a team to plan the experiment. The engineer supplies the technical knowledge in the applied field and the statistician, knowledge of variability and of how to detect and identify evidence that may be associated with assignable causes. Instances have occurred in my experience where the average of 100 measurements in a cooperative experiment was subject to less expected variation than the average of 10,000 by the customary method before the advice of the statistician was sought.

Attention has also been directed to the kinds of statistical measures that are appropriate for use while manufacturing a product as contrasted with those that are appropriate for use in research and development work. How these fields are bridged by production research is also indicated, pointing out how valid tolerance limits for a product may be established. Use of limits established in this way is suggested as a substitute for existing empirical methods of selecting specification limits for individual units of product.

Figure 1—**Operational View of Product Quality Control**

The concepts and statistical measures that have been selected for consideration in this survey are those that can be illustrated by pictures or patterns in observed data. Since such pictures are or may be easily related to the experience of the engineer, it is much easier to sell the basic principles to him. This is very important because he is really the ultimate consumer of the conclusions reached from the data and in many instances must be convinced that the conclusions are reasonable. The fact that we are able to tie particular measures to the kinds of patterns that he has associated with trouble in the past gives assurance that he can rely on our procedures of analysis.

AN OPERATIONAL VIEW OF QUALITY CONTROL

This story would not be complete if we did not explain what we mean by the field of quality control, as we conceive it as engineers. If we think of a single product, we find that we go through the following steps before we have assurance that the process of manufacture is satisfactory:

1. Determine the quality that is wanted through *consumer research*,
2. Perform *research and development* work to devise means for fulfilling these wants at a reasonable cost,
3. *Design and specify the product* selected and in so doing set tolerance limits,
4. *Make the product* that is specified,
5. *Inspect the product* for conformance to design and specification, and
6. *Test the product in service (operational research)* to see that it satisfies the wants of the user in an adequate, dependable and economic way.

This procedure is one in which changes are constantly taking place. New wants are continually being discovered, new researches are being undertaken, new and changed designs are required, improvements and changes in production processes and inspections are necessary, and finally, what is made must be tried out in the field where changes in consumer wants will inevitably be found. The connected nature of this process is indicated in Fig. 1.

From this picture, we may assume that the work of the engineer is never done. His objective, however, is clear. His goal is to attain an *economic state of statistical quality control*. The degree to which he can approach this goal is dependent on his ability to locate, identify and eliminate assignable causes of variation. Experience has shown that the analytical procedure given here has been an important aid for approaching closer to this goal than we have ever been before.

The analysis of the situation provided by this article is a first step toward solving the general problem of controlling quality. It is clear that we must enlist the aid of others in this work. There are parts of the problem that are for engineers and statisticians but there are also parts for the psychologist, the chemist, the physicist, the mathematician, experts in sampling, experts in opinion polling, and experts in many other fields. It is clear that no one person from one field will be sufficiently capable to be able to work out the whole of the problem. It must be a cooperative venture with, I believe, the engineer taking the lead because he has so much at stake on the outcome.

SHORT COURSE ANNOUNCEMENT

A Statistical Quality Control Short Course will be conducted at the Georgia Institute of Technology, February 27-March 6, 1953. This will be a basic course to acquaint industrial personnel with techniques for putting SQC into operation. For information write to C. H. Taylor, Short Courses and Conferences, Georgia Institute of Technology, Atlanta, Georgia.

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Book Reviews

A. C. Cohen, Jr., *Editor*

Correspondence and suggestions concerning book reviews should be sent to:
Professor A. C. Cohen, Jr.
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University of Georgia
Athens, Ga.

THE DESIGN AND ANALYSIS OF EXPERIMENTS

Oscar Kempthorne; John Wiley and Sons, Inc., New York, 1952. 631 + xix pages. $8.50. Reviewed by Charles A. Bicking, Ordnance Engineer, Office, Chief of Ordnance, Washington 25, D. C.

Although this is not a book for the beginner, it should be a part of the library of everyone seriously interested in experimental methods. It forms an admirable supplement to the available "cook-book" types, exemplified by Brownlee, and the basic manual of examples of experimental designs by Cochran and Cox. Although not as rich in examples as "Experimental Designs," it is a more solid presentation from the standpoint of exposition of underlying assumptions and of the theoretical proof of techniques.

Very brief introductory chapters cover the role of statistics in the scientific method, the principles of experimental design, elementary statistical notions, and an introduction to the theory of least squares. The coverage of design techniques is complete and develops very logically from the simplest treatment to the most complicated concepts of groups of experiments and treatments applied in sequence. The treatment of each subject is rather succinct so that, without mentioning each of the 25 major chapter headings, the scope of techniques covered may be listed as follows: The general linear hypothesis, the analysis of multiple classifications, randomization, Latin Squares including plot techniques, confounding of factorial experiments, split-plot experiments, fractional replications, lattices and incomplete block designs, experiments on infinite populations and groups of experiments, and treatments applied in sequence.

Each chapter is carefully referenced and in many instances further related reading is suggested. Since the approach to the problems is that of a mathematical statistician, the symbolism may be unfamiliar to many working in industrial statistics and the few numerical examples involve problems from agricultural or biological sciences. These factors do not make the book easy for an engineer to read. However, they do not detract from its primary usefulness as a source book.

In addition to complementing earlier texts on design of experiments by answering the question *why* certain practices should be followed, this book has other worthwhile features. The shortcomings of various techniques are given as frank a treatment as the recitation of their advantages. This is extended in some instances even to the listing of specific problems yet to be solved. Another feature of value is the habit which the author has of pausing from time to time to make a comparison between the capabilities of the different designs available.

One slightly disturbing element is the occasional insistence of the author on the importance of the convention of using only certain symbolism lest the result be hopeless confusion for most people. Again, in the introductory chapter a question may be raised about the point of view that the determination of the relevant aspects of the whole (experimental) situation and the actual formulation of the hypothesis are a matter of intuition or genius. By and large, however, the book does not leave the impression that it is directed only toward a preferred class of mathematical statisticians but is written with the experimenter and consulting statistician also in mind.

INDUSTRIAL PROCESS CONTROL BY STATISTICAL METHODS

John D. Heide; McGraw-Hill Book Company, Inc., New York, 1952. 297 pages. $6.00. Review by Frank E. Grubbs, Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland.

This book represents one of many treatises covering the application of statistical quality control as applied to industrial operations that have been written mostly by the scholar and not by the quality control engineer in industry or the practitioner. The current book is one by an "Industrial-Statistical Analyst" or quality control engineer. The book itself is primarily non-technical in nature, but it purports to supply the quality control engineer with the necessary statistical background, formulas, tables of factors, etc., which are a requisite counterpart to the application of control chart principles. The chapters are headed Introduction, Presentation of Data, Process Frequency Distributions, Control Charts, Limit Lines, Operating Specifications, Technical Problems, Study of Process Data, Factory Installations, Practical Program Aids, Factory Interpretation of Charts, Organization and Administration, Quality Reporting and Quality Rating, the Evaluation of Test Procedures and Test Results. The appendixes include glossaries of symbols and terms, methods of calculating the average and standard deviation, tables of the normal distribution, a section on the binomial expansion, and a section entitled "Standard Operating Procedure Manual on Procedure for Establishing and Maintaining Measurement Control."

The main technique or quality control weapon advocated in the book is the control chart procedure along with allied topics. In this connection, the author discusses, for example, control charts for individuals, averages, ranges or standard deviations, control charts for number of defectives and number of defects. Approximately one-half of the book is devoted to the control chart technique and procedures, and many practical examples from the author's own experience over the past ten years are included. Also, at the end of each chapter the author has listed a sizeable number of exercises for the reader or student to work on. Actually, the techniques developed in this part of the book are to be found in most of the quality control books now on the market, and, for this reason, it is the opinion of the reviewer that the elementary principles developed in this part of the book could well have taken up much less space. As a matter of fact, many of the principles covered were published during the

early 1940's and are therefore quite familiar to many in quality control work today. Perhaps the author has endeavored, however, to exhibit completeness in his presentation; i.e., to outline SQC procedures and to warn the quality control engineer of all of the major pitfalls he may likely encounter in setting up such a quality control system in an industrial establishment. The reviewer gathers in this connection that much experience had to be gained in handling the "knotty" administrative problems before the author could proceed to place quality control principles on a sound basis in the various plants of the U. S. Rubber Company and especially before they were accepted as being both valuable and economical.

The reviewer would judge the last few chapters which have to do with Study of Process Data, Factory Installations, Interpretation of Charts, Organization and Administration, and Quality Rating and Reporting as being a newly published contribution and perhaps the more valuable part of the book at the time of its publication. The reason for this statement is that the author has pointed out a great many problems which will arise in many quality control applications — the special training and education of factory personnel, the matter of securing proper authority for SQC installations and changes, the necessary coordination of activities, the problem of skepticism on the part of workers and management which arises during the trial period of SQC, etc. Steps which should be followed in making the quality control system work in spite of these difficulties are ably discussed by the author. The discussions in this part of the book cover many of the most important practical aspects of any quality control program and hence the content of the above chapters is of considerable importance. This part of the book demonstrates just how slowly SQC applications are accomplished because of practical entanglements.

The rather limited treatment of the concepts of accuracy, precision of measurements, "testing error," reference standard, etc., appear to be somewhat inadequate to the reviewer although perhaps the author did not intend to cover these topics in their involved but necessary technical detail. Perhaps the main purpose of the chapter headed "Evaluation of Test Procedures and Test Results" is to acquaint prospective users of quality control with the above concepts or to give them a superficial glance at the types of problems which may be encountered. The reviewer prefers "standard error of measurement" to the term "testing error" used exclusively by the author of the book.

Apparently, the prospective readers or users of the book will be beginners in quality control work, who will apply the techniques, and management representatives. Indeed, it would appear that from this book, management would get a good picture of the problems it would be faced with if it expects to embark on a program in the application of statistical process control to industrial operations. It is believed that the quality control engineer, on the other hand, will have to look elsewhere for many technical details which will be necessary to solve the more involved problems that will arise from time to time in some industrial applications.

FACTS FROM FIGURES

M. J. Moroney; Pelican Book A236. Penguin Books, 3300 Clipper Mill Road, Baltimore, 1951. viii + 473 pp. $1.25. Review by Gregor Sebba, University of Georgia, Athens, Georgia.

Leave it to an Englishman to write a solid, thorough, reliable introduction to statistics and quality control and make the job sparkle with wit and common sense. And leave it to a British publisher to put out this very technical book in a cheap paperbound edition addressed to intelligent readers in general. Mr. Moroney is all of an industrial consultant, an associate professor in a department of mathematics, and an amateur politician who ran (or, as they say over there, "stood") for Parliament and lost in a resounding way—not undeservedly, if we may judge from his book. For Mr. Moroney is a man of independent views who has the disconcerting habit of testing before accepting, which makes him an excellent quality control man but augurs ill for his political future.

He describes his book as "a conducted tour of the statistician's workshop. The reader is shown many tools and machines, given a quick explanation of their purpose and method of operation, and then encouraged, after watching the craftsman for a while, to try for himself." It is a very prolonged tour, at that. The reader is rather quickly

A New Book on Statistical Analysis . . .

"Statistical Design and Analysis of Experiments for Development Research" by Donald Statler Villars, Research Scientist, U.S. Naval Ordnance Test Station, Inyokern, China Lake, California.

Based on courses and lectures given at various universities, this book summarizes the fundamental principles involved in the design of efficient experiments. A journalistic style is employed so that the reader may almost immediately begin applying various analyses to his own data without having to go any deeper into the subject than he desires. Major emphasis is placed on the techniques of small sample statistical analysis for use in laboratory and development work, rather than on large sample analysis applicable to plant or mass production operation.

Of particular value is a detailed study of replication degeneracy, a design where several different types of treatments are repeated to differing extents. An understanding of the simple principle involved in this design will prevent the beginner from making erroneous "statistical" conclusions. In addition, the author formulates a rational system for determining the correct method of analyzing variance. New and extended tables of variance components are worked out, and a detailed description is given of the technique for applying these components to determine the appropriate error estimate for a legitimate significance test.

Many tables of actual test data and typical calculations are used to illustrate the text. For the convenience of the beginner, a comprehensive glossary of terms is included, and the book also contains lists of typical problems with their solutions, and both author and subject indices. This 5½ x 8½ inch book contains 472 pages, is cloth bound and sells for only $6.50. Order your book on money back guarantee today. . .

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taken through the more humdrum departments of elementary probability, charts ("The Magic Lantern Technique"), averages and dispersion. He pauses long enough to get well acquainted with the binomial, Poisson and normal distributions. Then the real work begins: control charts, acceptance sampling, tests of significance, estimation and confidence limits ("How to be Precise Though Vague"), the chi square distribution, and correlation. There follows a brief chapter on "Time Series and Fortune Telling," written by Mr. Moroney the amateur politician with the cooperation of Professor Moroney (time series analysis and forecasting is "a vile superstition beyond anything imaginable in the middle ages"). After an excellent chapter on ranking methods the book raises to a climax of clear, outstandingly skillful exposition of analysis of variance and covariation which takes up some 70 pages.

This is a truly introductory book, designed to make the reader fully understand the tools available, and their statistical and other limitations. Instead of giving the usual standard tabular setups and computational techniques, Mr. Moroney goes through each topic by way of a carefully reasoned, ingeniously presented step-by-step discussion, leaving it to the reader to find practical worksheet layouts, etc., elsewhere. The book requires no mathematics beyond the most elementary algebra. It is proof of the author's didactic skill that the reader is kept interested from beginning to end, and winds up with the distinct desire to dig deeper. Mr. Moroney's humor will strike different people differently, and some very English examples will fall on stony ground with Americans. Some minor errors have slipped by. But the rich, outspoken comment on matters of shop psychology, use and abuse of specific statistical tools, and fallacies arising from a too narrow statistical approach amply make up for these small faults.

In conclusion, Mr. Moroney advises young people to learn something about statistics as soon as they can. "If you are older and already crowned with success, see to it that those under your wing . . . are encouraged to look into this subject. In this way you will show that your arteries are not yet hardened, and you will be able to reap the benefits without doing overmuch work yourself. . . ." One good way of accomplishing this is for the successful older man to give copies of this book to his young hopefuls, with the compliments of the company.

QUALITY CONTROL BY STATISTICAL MEHODS

G. Herdan. Thos. Nelson and Sons, Ltd., London 1948. xi + 214 pp., Appendices I to XII, 21 shillings. Review by G. M. Brown, Associate Professor of Mathematics and Statistics, The Atlanta Division, The University of Georgia, Atlanta, Georgia.

This book was the outcome of a series of lectures to groups of people engaged in industrial production, probably over a period of time including the years of World War II. It develops along the lines of translating problems of production and inspection into the language of statistics. In Chapter I, the author discusses "The Laws of Chance and the Normal Law of Errors," introducing the classic example of ballistics, in talking of the "aims" of industrial quality control. In Chapter II, control charts are discussed, using statistical (so called probability) limits, as initiated by Pearson and the "British School" and incorporated in British Standard Procedures, these limits being a modification of the empirical 3-sigma limits of American Standard Procedures. A short discussion of Shewhart's basic theory, on the justification of the 3-sigma control limits, would have been appropriate at this point. Several control charts for averages are shown, with (a) process under statistical and economic control, (b) lack of statistical control, (c) faulty machine setting, (d) change in variability of product due to assignable causes, (e) process under statistical but not under economic control, (f) process showing economic control, but lacking statistical control, (g) chart showing trend. Only six of the 33 pages in this chapter are devoted to a discussion of range charts. Control charts for sigma are not mentioned.

In Chapter III, the straight line probability graph of the cumulative normal curve is introduced. Here, an unusual application of this curve (as a probability graph) is made to quality control. From such a graph, one can determine the mean and sigma and can also estimate the percentage of the bulk that is within or without specifications. In Chapter IV, the author applies analysis of variance techniques to problems in quality control. Significance, as indicated by the F ratio at the five percent level would indicate a process out of control. The "new" technique is similar to the control chart technique in its principal features. For example, the samples of n items (the subgroups) are selected in a non-random manner, with respect to the total population. Chapter V opens with a discussion on trends and a new but presumably rational type of subgrouping, according to a variable which is correlated with the characteristic sampled. The author illustrates with the continued firing of ammunition from a steadily wearing gun barrel. In this case, the central line, ("wear line"), as well as the control limits are inclined. The control limits here have direction as well as position. The chapter is thus appropriately called "The Compass of Chance."

Chapter VI discusses "fraction defective" or qualitative charts. Herdan attempts to bring qualitative control into line with quantitative control, by averaging for defectiveness over n samples of n′ items each, and obtaining limits for these averages. In order to obtain such limits he makes use of the following properties: (a) the distribution of means of n samples of n′ items each chosen at random from a Poisson population, follows the Poisson law; (b) the square root of the variate in a Poisson distribution has a variance which is almost independent of the mean and is approximately constant. The use of the square root of the mean distribution has proven very useful in cases difficult to handle by the usual control chart method. If a distribution of sample means follows the Poisson law, and this distribution is transformed into that of the square root of means, the variance of the latter will also be approximately constant. Number defective charts are set up for square roots of averages for samples of four and eight respectively, using both random, and non-random sampling schemes. The greater the number of samples included in the computed "average defectiveness" of samples, the more sensitive is the method of distinguishing between erratic and systematic changes of quality.

In Chapter VII on statistical sampling inspection, the author discusses how small sample quality deviates from the quality of the lot. Further, he indicates schemes for judging lot quality from sample quality and vice

versa. He also points out that with probability graphs, as applied to quantitative sampling, stress is laid on obtaining information as to the percentage of product within specifications. Of secondary importance is the nature of the lot distribution. In qualitative sampling, however, the intention is reversed. In the latter case, Poisson summation graph paper is used. In Chapter VIII, "The Shorthand of Inspection," consumer's and producer's risks are explained with illustrations. The Dodge-Romig tables for single- and double-sampling schemes are next examined in some detail. A modification of the tables is outlined with an appropriate illustration to fit the case when an article is inspected for a number of defects which occur simultaneously. Finally, in 12 appendices, the author gives specimens of the charts and tables normally used in quality control work as well as some mathematical formulas and developments.

I disagree with the author's contention that a high school background only is necessary for the proper understanding of his book. It is not replete with mathematical developments at every turn of a page. Neither is it perfect in style nor devoid of errors, but it is nevertheless worthy of serious study. In a relatively small volume he has packed some thought provoking and yet extremely interesting ideas, fit for the mind of the serious statistician, no less for the layman in statistical thinking who is still struggling valiantly to marry old and new statistical theory to his manifold everyday problems.

NEW BOOKS RECEIVED

CONTROL ESTADISTICO EN LA PRODUCCION INDUSTRIAL Y EN LA DIRECCION DE EMPRESAS by Guido O. Liserre and Paul Conde, 1952. Rosario, Argentina. 112 + xii pp. paper bound.

HANDBOOK OF ENGINEERING FUNDAMENTALS, Second Edition, by Ovid W. Eshbach, 1952. John Wiley and Sons. 1423 + 52 + x pp. $10.00.

PRODUCTION FORECASTING, PLANNING AND CONTROL by E. H. MacNiece. John Wiley and Sons, New York. 305 + xiii pp. $5.50.

METHODS OF OPERATIONS RESEARCH by Philip M. Morse and George E. Kimball. John Wiley and Sons, New York. 158 pp. $4.00.

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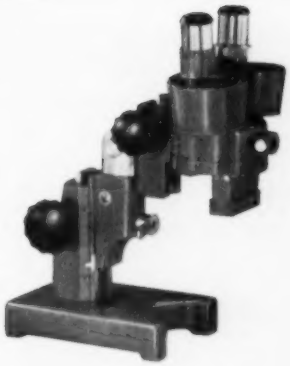

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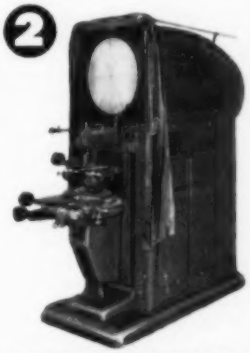

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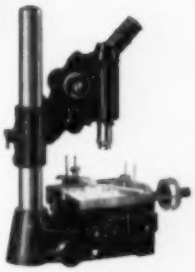

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On matters concerning the Bibliography Department, send correspondence, suggestions, and contributions to:

Mr. Joseph Movshin
9220 Old Bonhomme Road
St. Louis 24, Mo.

APPLICATION—
AIRCRAFT INDUSTRY

QUALITY CONTROL: JOB-LOT OR BIG TIME, Dorian Shainin
(Aviation Age—v. 18, n. 2, Aug. 1952, p. 42)

This article discusses the concept of SQC in general terms. Advantages to the aircraft industry with due consideration to the job-lot type of production is given. (First part of a two-part article.)

PRODUCT QUALITY IS BUILT-IN, Dorian Shainin
(Aviation Age—v. 18, n. 3, Sept. 1952, p. 38)

Two methods for the statistical control of quality of manufactured products are discussed by Mr. Shainin. These are, particularly, the average and range chart as used in the simpler form of the sum and range chart, and the Lot Plot method. (This is the conclusion of the two-part article.)

APPLICATION—
METAL WORKING

5TH ANNUAL QUALITY CONTROL FEATURE ISSUE
(Tooling & Production—v. XVIII, n. 7, Oct. 1952)

A series of articles on the value and methods of application of SQC. These include:

Statistical Quality Control in the Camillus Cutlery Company, by Frank Caplan, Jr. "The establishment of a quality control program with its attending decrease of rejected components."

Quality Control, by Lester F. Spencer, Landers Frary & Clark. "When starting a quality control program the primary object is the prevention of defects."

Statistical Sampling and Corrective Action Improve Quality, by J. Manuele, Director, Headquarters Quality Control, Westinghouse Electric Corp. "A successful quality control program is predicated on the cooperation of inspectors and foremen."

A Progress Report on Quality Control at Lamson & Sessions, by Charles R. Kendel, The Lamson & Sessions Co. "The successful application of quality control to the cadmium plating of bolt threads is described."

Control of Quality in a Forge Shop, by C. H. Snyder, Pittsburgh Forgings Co. "Details of quality control program, starting with the receipt of steel, through forgings."

What is Quality Control? by Clifford W. Kennedy, Federal Products Corp. "Quality control is primarily the timely, accurate and inexpensive detection of deviation from specification."

APPLICATION—
MISCELLANEOUS

QUALITY CONTROL—WATCHDOG OF PREVENTIVE MAINTENANCE, F. C. Schulze, Chief Inspector, Hunter Spring Co.
(Mill & Factory—v. 51, n. 1 and 2. Part 1, July 1952, p. 192. Part 2, Aug. 1952, p. 93)

At Hunter Spring Company the control chart and the frequency distribution are used to prevent tool and machine wear that would produce defective parts. Examples of applications include:

- Studies of tool wear on coiling machines
- Detection of wear of grinding wheel ways
- Determination of when to check and adjust testing machines

The article is illustrated with a number of charts and pictures.

THE STATISTICAL CALCULATION OF BURSTING STRENGTH, E. R. Hoffman
(Tappi—v. 35, n. 1, Jan. 1952, p. 4)

The use of control charts (X & R) to control the properties of various grades of paper. A method of relating bursting strengths to standard hypothetical values is used.

CORRELATION

SIMPLE CORRELATION IN THE FOUNDRY, W. K. Bock, Research Engineer, National Malleable & Steel Castings Co., Cleveland
(Foundry—v. 80, n. 8, August 1952, p. 104)

Correlation is described in simple detail as a useful tool for securing information in the foundry. The use of significance tests and the limiting requirements for such tests are discussed. A detailed illustration used is the correlation of the Charpy value and the Rockwell C hardness for steel.

Statement of the Ownership, Management, Circulation, Etc. Required by the Act of Congress of August 24, 1912, As Amended by the Acts of March 3, 1933, and July, 1946.

Of "Industrial Quality Control," published bi-monthly at Milwaukee, Wisconsin for September, 1952.

1. The names and addresses of the publisher, editor, managing editor and business manager are: Publisher, American Society for Quality Control, Inc., 70 East 45th Street, New York 17, N.Y.; Editor, Mason E. Wescott, Rutgers University, New Brunswick, New Jersey; Managing Editor, George R. Foster, 6123 Plankinton Bldg., 161 West Wisconsin Avenue, Milwaukee 3, Wisconsin; Business Manager, Raymond S. Saddoris, A. O. Smith Corporation, Milwaukee 1, Wisconsin.

2. The owner is: American Society for Quality Control, Inc., 70 East 45th Street, New York 17, N. Y.

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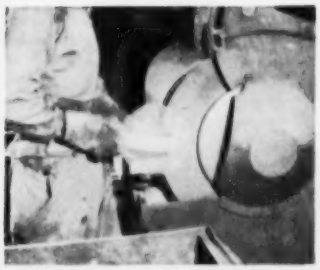

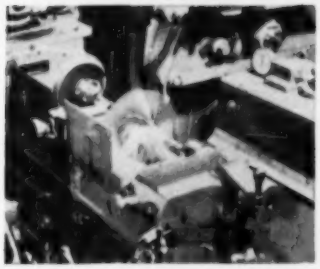

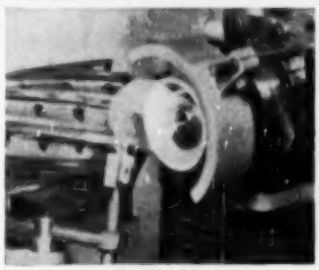

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Making better products to make other products better

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ENGINEERING AND EXPERIMENTS

ON THE EVALUATION OF NOISE SAMPLES, A. J. F. Siegert, The Rand Corporation

(J. of Appl. Phys.—v. 23, n. 7, July 1952, p. 737)

A mathematical development of a test for the estimation of whether a sample of noise measurement can be assumed to come from a Gaussian noise distribution with predetermined parameters.

AN ANALYSIS OF SOME FAILURE DATA, D. J. Davis, The Rand Corporation

(J. of Am. Stat. Assoc.—v. 47, n. 258, June 1952, p. 113)

Discussion of the techniques employed to analyze failure data from human, mechanical, and electronic operations. The appendix includes distributions of failure data for such items as clerical errors, automatic calculating machine failures, electrical equipment failures, radar set component failures, and bus motor failure.

MANAGEMENT AND PERSONNEL

HOW A SMALL SHOP USES QUALITY CONTROL, Don Spath, Chief Inspector, General Products Corporation, Jackson, Michigan.

(The Iron Age—v. 169, n. 25, June 19, 1952, p. 143)

Mr. Spath describes the use of Q C in a plant employing only 180 workers. Several advantages of using quality control methods are listed. Certification of quality has been possible for a number of different parts. Pictures of several charts and some of the products manufactured are included in this article.

IS YOUR PRODUCT TOO FUSSY? J. M. Juran

(Factory Manage. and Maint.—v. 110, n. 8, Aug. 1952, p. 125)

In judging the quality of certain subjective characteristics of a product, it is important to consider requirements and interests of a customer rather than the inspector's or engineer's opinions. A method of charting customer vs. inspector objections to a product is given.

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SEQUENTIAL SAMPLING

A NOTE ON THE SEQUENTIAL ESTIMATION OF MEANS, D. R. Cox

(Proc. of the Cambridge Phil. Soc.—v. 48, Part 3, July 1952, p. 447)

The mathematical development of a method for finding a population mean from a sequential sampling procedure.

THEORY AND APPLICATION—GENERAL

QUALITY CONTROL METHODS, Dorian Shainin, Hamilton Standard Division, United Aircraft Corporation.

(PART III. "How and Where to Control," *Machine Design*, v. 24, n. 9, Sept. 1952, p. 168)

(PART IV. "Human Elements in Production," *Machine Design*, v. 24, n. 10, Oct. 1952, p. 193)

Part III discusses the use of the p chart as a guide to the best places to establish more specific controls. A convenient graph to find the control limits for the p chart is given. The X and R chart and the Reset-Run charts are introduced.

Part IV discusses some of the effects of statistical control methods on production personnel. The use of such methods to effect favorable results is indicated. The Lot-Plot method of sampling is described in some detail.

Parts I and II of this series were reported in the November 1952 Bibliography Section. This series is to be continued.

STATISTICAL EVALUATION OF RATIONAL AND STRATIFIED METHODS OF SAMPLING, James V. Strela, Thompson Products, Inc.

(The Tool Engineer—v: XXIX, n. 2, 3 and 4)

Part I. Aug. 1952, p. 37

Part II. Sept. 1952, p. 61

Part III. Oct. 1952, p. 55

Part I. Mr. Strela discusses the logic of the statistical methods of sampling. The quincunx (sampling machine) is used to illustrate sampling problems. The effect of sample size upon the sample distribution is developed in some detail.

Part II. The use of the range as a measure of distribution spread is discussed. The $\bar{X}$ and R chart are developed along with the concept of control with respect to an unknown standard.

Part III. The frequency distribution is related to control chart indicators. Illustrated with detailed interesting comparison charts.

This series will be continued.

STATISTICS

REVIEW OF LITERATURE OF SYSTEMATIC SAMPLING, W. R. Buckland
(Royal Statistical Society Journal—v. 13, n. 2, 1951, p. 208)

ON THE MOST ECONOMICAL SAMPLE SIZE FOR CONTROLLING THE MEAN OF A POPULATION, H. Weiler, New South Wales University of Technology
(Annals of Math. Stat.—v. 23, June 1952, p. 247)

EXPERIMENTAL DESIGNS FOR SERIALLY CORRELATED OBSERVATIONS, R. M. Williams
(Biometrika—v. 39, May 1952, p. 151)

COMPARISON OF TWO APPROXIMATIONS TO THE DISTRIBUTION OF THE RANGE IN SMALL SAMPLES FROM NORMAL POPULATIONS, E. S. Pearson
(Biometrika—v. 39, May 1952, p. 130)

TIME INTERVALS BETWEEN INDUSTRIAL ACCIDENTS, B. A. Maguire and others
(Biometrika—v. 39, May 1952, p. 168)

ANALYSIS OF OBSERVATIONS, E. W. Bastin and C. W. Kilmister
(Royal Society of London, Proc. —v. 212, May 22, 1952, p. 559)

ON THE CONSTRUCTION OF TABLES FOR MOVING-AVERAGE INTERPOLATION, W. R. Thompson and C. S. Weil
(Biometrics—v. 8, Mar. 1952, p. 51)

AUTOMATIC MULTIPLE POINT CHECKING IN MODERN MASS PRODUCTION, G. Bradet
(Microtecnic—v. 6, n. 2, 1952, p. 125)

REPORTED—NOT REVIEWED

STATISTICAL PROPERTIES OF PRESSURE CHANGE ALOFT, W. Kaciak and P. A. Langwell, New York University
(Journal of Meteorology—June 1952, p. 172)

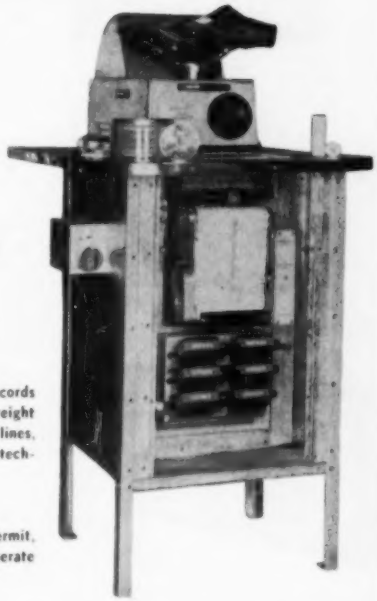
A discussion of tests of normality for certain data used in pressure change measurements.

"DATAMATIC" WEIGHT CALCULATOR

GRAPHS—
IN PLOTTING EACH TEST WEIGHT ON STRIP CHART

AVERAGES—
IN CALCULATING AND REGISTERING THE AVERAGE FOR YOUR GROUP SAMPLING

TOTALIZES—
IN INTEGRATING OVERWEIGHT & UNDERWEIGHT AMOUNTS AND UNIT COUNT AMOUNTS INTO SEPARATE ELECTRIC COUNTERS



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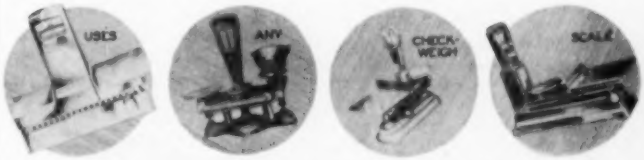
does all the work, produces all the records required for statistical or simple weight control at a single or at multiple lines, when using sampling inspection techniques.

THE "DATAMATIC"
(likened unto cash registers) would permit, literally, a 14 year old child to operate S.W.C. for several production lines.



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is being successfully used for S.W.C. on 14 production lines (Same product).

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is being successfully used for S.W.C. on
4 production lines (one product)
2 production lines (second product)

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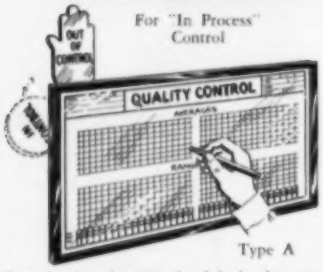
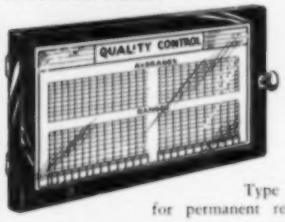


Type A

Type A—chart form is placed back of acetate window. Actual recording is with grease pencil on the acetate. Erasable.



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for permanent records

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From the Scrap Box

OPERATIONS RESEARCH SOCIETY OF AMERICA

The first issue of the Journal of the Operations Research Society of America appeared in November, 1952. It consists primarily of a report on what occurred at the Founding Meeting of ORSA on May 27, 1952. Included are two invited papers by Bernard O. Koopman and Russell L. Ackoff and a summary of other activity by Thornton Page, the Editor of the new journal.

The formal papers relate to the fields of Mathematical Probability and Statistics which are also basic to Statistical Quality Control. In the examples of non-military use of operations research methodology, summarized by Dr. Page, are instances relating to merchandising, inventory control, and "efficiency" engineering. The analysis appears to be primarily by the method of revision of basic assumption by breaking the operation into component elements that may or may not be interrelated. These problems were all of the specific variety. An indication was also given that operations research could be useful at company headquarters in dealing with broad problems where company policy and like items are important.

The officers of the new society are:

President—Philip M. Morse, Massachusetts Institute of Technology

Vice President—Robert F. Rinehart, Case Institute of Technology

Secretary—John B. Lathrop, Arthur D. Little, Inc.

Treasurer—Alfred N. Watson, Massachusetts Institute of Technology

The American Society for Quality Control takes this opportunity to extend its best wishes to this new society.

BIBLIOGRAPHY OF WARTIME QC REPORTS

This is a suggested list of references on the subject. Additional information may be obtained by writing to the Office of Technical Services, Department of Commerce, Washington 25, D. C.

Orders for reports which are available in printed or mimeographed form should be directed to the Office of Technical Services, Washington 25, D. C., accompanied by check made payable to the Treasurer of the United States. Orders for other types of reproduction (microfilm, enlargement prints, photostat) should be forwarded directly to the:

Library of Congress
Photoduplication Service
Publication Board Project
Washington 25, D. C.

accompanied by a check made payable to the Librarian of Congress.

PB13212 U. S. QUARTERMASTER CORPS, "Inspection Handbook on Sampling for Quality Control," (Inspectors' edition) 1945. 55p. illus. Mi $1.00 Ph $4.00 (V. 1, p. 1445)

PB17522 WORKING, HOLBROOK and OLDS, E. G., "An Introduction to Statistical Methods of Quality Control in Industry, and Outline of a Course of Lectures and Exercises," Apr. 1944. 80 p. forms, tables. Mi $1.00 Ph $6.00 (V. 2, p. 78)

PB21171 U. S. FRANKFORD ARSENAL, PA., "Statistical Methods of Quality Control," Aug. 1943. 15p. Mi $.50 Ph $1.00 (V. 2, p. 546)

PB21172 U. S. FRANKFORD ARSENAL, PA., "Discussion of the Application of Statistical Methods of Quality Control," n.d. 6p. Mi $.50 Ph $1.00 (V. 2, p. 546)

PB21173 U. S. ARSENAL, FRANKFORD, PA., "Procedure for Computing the Central Line on a Control Chart," n.d. 5p. charts. Mi $.50 Ph 1.00 (V. 2, p. 216)

PB27165 FIZZELL, J. A. and others. Quality Control Reports: Nos. 1-12. May-Sept. 1945. 222p. tables, graphs. Mi $5.00 Ph $15.00 Mimeo $2.00 (V. 2, p. 766)

1. Introduction of Statistical Quality Control at Illinois Testing Laboratory
2. Organizations Concerned with Statistical Quality Control
3. Statistical Quality Control at the St. Louis Division of American Stove Co.
4. Quality Control at the Lukas-Harold Corp.

5. Statistical Quality Control in Radio Manufacture
6. Quality Control at the Hoover Ball and Bearing Co.
7. An Adaption of Statistical Quality Control at Aldens
8. An Application of Statistical Quality Control at the John Deere Tractor Co.
9. Statistical Quality Control at Lockheed
10. Some Aspects of Quality Control in the Steel Industry
11. Bibliography of Statistical Quality Control
12. Some Experiments Illustrating Principles of Quality Control

PB39492 HARRIS, F. P., "Quality Control at Picatinny Arsenal," Mar. 1946. 263p. photos, forms, graphs. Mi $6.00 Ph $18.00 (V. 3, p. 292)

PB39493 COHEN, A. C. Jr., "Quality Control Through Sampling Inspection," Oct. 1942. 46p. charts, tables, curves. Mi $1.00 Ph $4.00 (V. 3, p. 119)

PB60934 WALLIS, W. A., "Inspection Plans for Ranges of 14 and 32 Observations," June 1945. 28p. graphs, tables. Mi $1.00 Ph $2.00 (V. 5, p. 241)

The volume and page reference given in parentheses at the end of each item refers to the "Bibliography of Scientific and Technical Reports," (V. 1-11) and "Bibliography of Technical Reports," (V. 12-date) where a brief abstract may be found. These bibliographies are on file at U. S. Department of Commerce Field Offices and most United States depository libraries.

ABBREVIATIONS: Mi — Microfilm; Ph—Photostat; Mimeo—Mimeograph; Enl Pr—Enlargement Print.

SHORT COURSE ANNOUNCEMENT

The Washington University, St. Louis, Missouri, announces an intensive training course in Quality Control which it will offer on March 19-27, 1953. The staff for this course will include Mason E. Wescott, Rutgers University; Donald J. Kaufman and Joseph Movshin, Washington University. The tuition will be $100.00 and will cover the necessary supplies and equipment. Further information can be obtained from: Donald J. Kaufman, Industrial Engineering Dept., Washington University, St. Louis 5, Missouri.

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Ames Dial Comparators make the inspection of duplicate parts an extremely simple, rapid and accurate operation. Ames Comparators are strictly impersonal in their accuracy — the results being in no way dependent on the skill or judgment of the operator. The pressure of the gauging members against the work is mechanically determined and therefore uniform.

Check the Ames Dial Comparators shown — one of them may solve a Quality Control problem for you.

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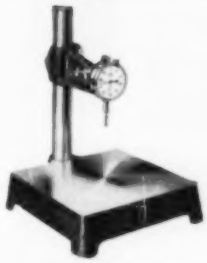
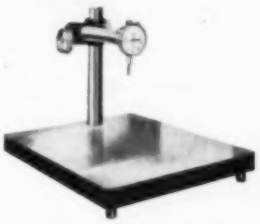
Ames No. 2 Dial Comparator is a compact, stable bench model for measuring non-yielding materials — sheet metal, glass, hard rubber. The 2" diameter table is adjustable to bring pointer to zero. *Ames No. 2W* is similar to the Ames No. 2, but is furnished with dead-weight contact pressure and contact areas to ASTM specifications for checking textiles, plastics, sheet rubber, etc.



Ames No. 13 Dial Comparator features flat-ground, cast-iron base of ample size for using V-blocks and locating fixtures for checking rounds, flats and odd shapes. Also, the No. 13 can be fitted with a fine adjustment for close setting. Accurately adjustable bracket holds any Ames Micrometer Dial Indicator.



Ames No. 130 Dial Comparator is designed especially for inspecting comparatively large parts. For this reason, the flat-ground steel base, the adjustable indicator support on which can be mounted any Ames Micrometer Dial Indicator, and the upright column are proportioned to suit the user's particular requirements.

Send us your Quality Control job specifications, and we will supply complete details and proposal without obligation.

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AMERICAN SOCIETY NEWS

EXECUTIVE COMMITTEE MEETING

At the invitation of the Midwest Conference Committee, the second Executive Committee meeting of 1952-53 was held during the Seventh Midwest Conference in Indianapolis. The meeting was held on Saturday, November 22, at the Hotel Claypool.

The following major actions were taken.

Committee Appointments

The appointment of Maj. Gen. Leslie E. Simon as chairman of the Shewhart Medal Committee to fill the vacancy left by the resignation of Warren R. Purcell was announced by the president and approved by the Executive Committee.

New Sections

It was noticed that the name of the 60th section of our Society was inadvertantly omitted from the last Society News column. This is the Louisville Section, which satisfactorily filled all requirements for admission immediately following the Annual Meeting.

Currently three new groups are applying for section status. These will be Sections 63, 64 and 65. The Executive Committee authorized the Executive Secretary to recognize the Eastern Nebraska and Richmond Sections just as soon as they have fulfilled the requirements. It is expected that the third group, Kansas City, will have completed the requirements in time to receive official recognition at the next Executive Committee Meeting.

Division Setup

The application for the organization of a Chemical Division was approved. The Charter for this division was presented by the president, Simon Collier, at the Princeton Conference on December 6. Vice-president Julian H. Toulouse was appointed trustee of the Division.

The Society now has two active divisions which have been set up to serve the needs of members in the textile and chemical industries. This plan of organization within the structure of the Society should result in enabling members in those industries to get together more conveniently on common problems. A tentative Constitution and By-laws for divisions were reviewed and have been forwarded to the Constitution and By-laws Committee and the Professional Ethics Committee.

Contributions to Shewhart and Brumbaugh Funds

The following contributions have been received for the Shewhart Medal and Brumbaugh Award funds:

Shewhart Medal	
Metropolitan	$50.00
Brumbaugh Award	
Metropolitan	$50.00
Georgia	$25.00

National Conventions

The Program Committee for the Seventh National Convention to be held at Convention Hall in Philadelphia on May 27, 28 and 29, 1953, announced completion of its work in lining up a program which it hopes will be sufficiently varied to appeal to all of the diverse interests in the Society.

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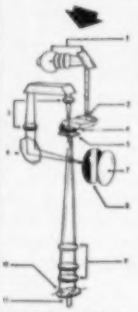

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One graduation represents 50 millionths.

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Upon recommendation of the General Convention Committee, as reported by the chairman, Wade R. Weaver, the Executive Committee accepted the invitation of the Montreal Section to hold the 1956 National Convention in Montreal, Canada, and that of the Michigan Section to hold the 1957 Convention in Detroit, Michigan.

Film Library

Another milestone in the development of Society services for its members is the establishment of a film library from which sections will be able to rent films at a nominal cost. To set up the library, the Executive Committee authorized the treasurer to purchase two copies of the Defense Department, 2-reel film on quality control. The library will be ready for operation as soon as these films are received. This will be approximately three or four months.

The rental fee for films was established at $2.50 per reel. In view of the anticipated demand, sections ordering films from the library must indicate the day or days the films will be used and will be asked to schedule showings so that they will be held not over a week. In addition to the rental fee, a fine of $1.00 per reel per day will be charged if the films are not postmarked within 24 hours after the last showing.

Since this venture represents a new service being offered by the Society, your help and suggestions regarding the type of films to be purchased for the library will be greatly appreciated. Please send your suggestions to Paul Robert, Treasurer, A.S.Q.C., c/o I.B.M., Endicott, New York.

THE MEMBERSHIP CORNER

Although the terminal date for renewing memberships is two months past, there should be no lessening of efforts to stimulate the interest of members who have not paid their dues. List of delinquent members have been compiled and forwarded to all Section Secretaries. This information should prove an invaluable aid to Membership Committees in contacting those individuals who have failed to renew. It cannot be emphasized too strongly that no membership should be allowed to lapse unnoticed. A specific example of what one Section is doing in this regard consists of not one, but two follow-up letters to all delinquent members. Not only do these letters enumerate several of the many ad-

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Federal, previous to the adoption of the Profilometer, checked surface finish visually; and after assembly tested for smoothness of operation under pressure run-out. Due to the exacting standards which the company maintains, this method often slowed production due to surface finishes. With the adoption of the Profilometer, however, surface finish of the bearing rings is now checked *before* final assembly. Result—precision quality control of bearings at all times during manufacture and a minimum of rejects prior to final bearing assembly.

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vantages of belonging to the ASQC, but they have enclosed a stamped, self-addressed envelope for convenience in returning a brief questionnaire. This questionnaire is to be returned to the Section in the event that the member cannot renew and is designed to aid in the determination of major factors responsible for loss of members.

Full advantage should be taken of the mid-year reduction in dues for new members. Potential members who have shown reluctance to join our Society should be made aware of the opportunity to become full-fledged participants in Society activities at a reduced cost.

Above all, Section Membership Committees must not be permitted to fall prey to the forces of lethargy which inevitably ensue after the rush of enthusiasm accompanying the first meetings of the new fiscal year. This is the time for careful planning and constructive review of mistakes and oversights, with an eye to sowing the seeds that will bear fruit in the form of membership renewals next September.

ELECTRONICS TECHNICAL COMMITTEE NEWS

The Electronics Technical Committee has been in operation a little over two years. During that time it has recommended electronics programs for the National Convention, has compiled a bibliography on electronics quality control articles, which is available on request from ASQC headquarters in New York City, has served when requested as a reviewing agency for the Editorial Board on electronics articles submitted for publication, and has been actively engaged in exploring the field of vendor certification in electronics. This latter project includes an attempt to reach an agreement for specific components on classification of defects, A.Q.L.'s, sampling plans, etc.

Frankly, we are not too sure just how many ASQC members are interested in this committee. Should we continue as a committee or organize as a division? Have the things we have been working on been of any great use to the members? Are there other projects that we should be looking into? These are some of the questions that we would like very much to have answered by you.

If you are interested in the committee or its work, or have any suggestions or ideas concerning it, please write to the chairman, Leon Bass, General Electric Co., Syracuse, N. Y.

BRUMBAUGH AWARD NOMINATIONS

Members of the Society are being requested by the Brumbaugh Award committee to submit the names of candidates for the 1952 Brumbaugh Award recipient. This award represents another way in which ASQC seeks to honor outstanding service to the Society. It is made each year to the author of the paper published in *Industrial Quality Control* that has been judged by the Brumbaugh Award committee to have made "the greatest development of industrial applications of quality control."

Nominations for the 1952 award should be limited to those authors whose papers were published in Vol. VIII of IQC (July, 1951—May, 1952, inclusive).

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Naturally the committee must rely heavily on the response of individual readers of IQC to assist it in recognizing that paper which has best met the criterion on which the award is based. Members of the Society are therefore urged to help the committee in its work by sending in immediately names for the 1952 award. Send your nomination now to the chairman of the Brumbaugh Award committee:

Halsey H. Kent
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Address all replies to box number references to: American Society for Quality Control Room 5036, 70 East 45th Street, New York 17, N. Y.

Engineer and statistician, registered, senior member ASQC, member ASME, experienced in analyzing research, process control and inspection problems by statistical methods. Wishes position in quality control or inspection division. Please reply to Box 9D1 at the above address.

SHEWHART MEDALIST NOMINATIONS

The Shewhart Medal committee announces that nominations are open for the 1952 medalist to whom the award will be made at the Philadelphia convention of the Society in 1953. The committee has expressed the considerations on which the nominations should be based as follows: "Outstanding contributions to the science of quality control, successful promotion and management of quality control programs, and service to the art and to the Society are among the factors which should be considered in selecting nominees."

Nominations for this award are invited from members of the Society, groups of members or Sections. Membership in the Society is not a requirement for eligibility, and it is desirable that nominations be made on a broad national and international scope rather than on a sectional basis.

The method used by the 1951 committee in handling nominations will be followed. After a nomination is received, the committee may request the nominator to furnish whatever supplementary information is available on the nominee's accomplishments to complete its own file. For a new nominee, the committee will request complete background information.

Although responsibility for selecting a medalist rests with the committee, it welcomes wide-spread interest in the nominations and needs the assistance of the members in naming suitable candidates from whom to choose. Deadline for the nominations is Jan. 31, 1953. Names of all nominees should be sent to the chairman of the Shewhart Medal committee:

Maj. Gen. Leslie E. Simon
Office, Chief of Ordnance
Washington 25, D.C.

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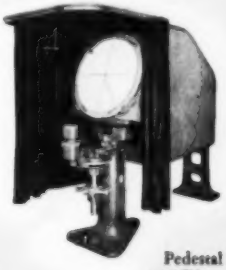

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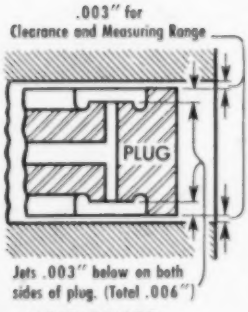

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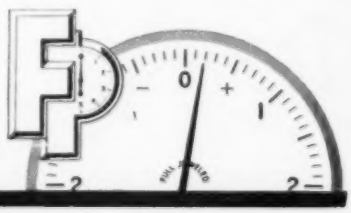

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